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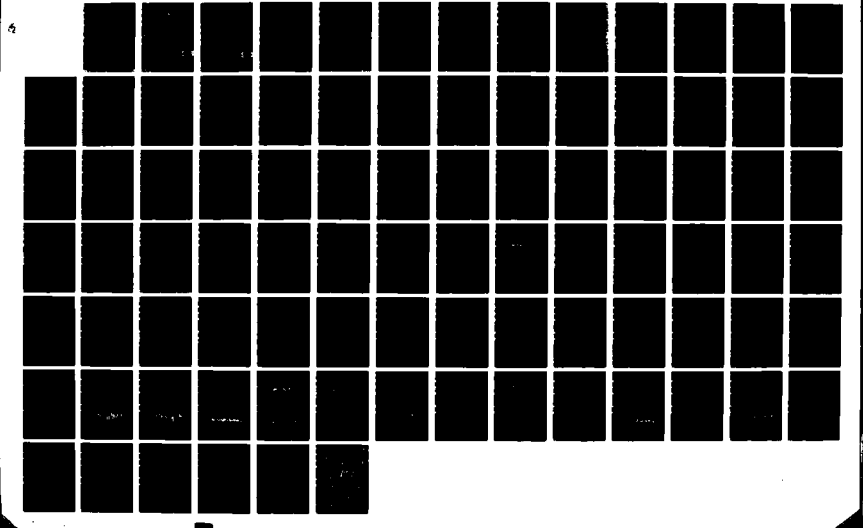

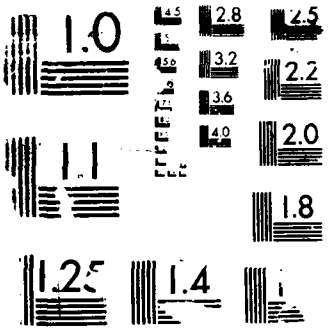

AN ANALYSIS OF PHYSIOLOGICAL DATA RELATED TO MOTION SICKNESS FOR USE IN A REAL-TIME MOTION SICKNESS INDICATOR

THESIS

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Captain, USAF

AFIT/GE/ENG/87D-16

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Electrical Engineering

Michael E. Drylie, B.S.
Captain, USAF

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Preface

The goal of this thesis project was to continue to collect physiological data on volunteers as motion sickness was induced, analyze the data collected, test and improve motion sickness indicators previously developed, for use in a real-time processor, and develop a method for testing the susceptibility to motion sickness for individuals.

I would like to thank Dr. Matthew Kabrisky, my thesis advisor for his patience and guidance. I am also thankful to Dr. William Czelen for sharing his circuit designs and knowledge in physiology. I would also like to thank Mr. Robert Durham for his assistance in obtaining supplies on short notice. I thank my thesis committee, Dr. Charles Hatsell and Dr. Bruce George. A very special thanks to the rest of this thesis team, Captains Edward Fix and Pierre Gaudreault, for their ideas, support, encouragement, and especially their friendship during these past months.

Finally, I would like to thank my wife Debbie, and my children, Tara, Michael Jr., Stephen, and James for the time and understanding they gave me during the last 18 months. Without their help, none of this would have been possible.

Mike Drylie

Table of Contents

List of Figures

List of Tables

Abstract

The existing data acquisition system was modified to produce better accuracy of the measured data. Additional sensors were added, sensor types and placements were modified. Circuits were modified to prevent overloading and to allow better tracking of the full range of expected physiological data points.

Previous indicators were evaluated as to their accuracy and degree of their usefulness in a real-time processor.

A susceptibility test was developed to allow the classification of a person as to their level of motion sickness susceptibility.

Physiological data were analyzed on the basis of their relationship with the onset of motion sickness, to develop a motion sickness indicator. theses

AN ANALYSIS OF PHYSIOLOGICAL DATA RELATED TO MOTION SICKNESS FOR USE IN A REAL-TIME MOTION SICKNESS INDICATOR

I. INTRODUCTION

Motion sickness is a perplexing and expensive problem for the military services and NASA. A trained aircrew member who must be grounded for air sickness represents a substantial loss (12; 16). Both the money spent training the individual and the time to train a replacement are lost.

It has been a problem for astronauts as well. Flight schedules are often disrupted to accommodate the problem (10). Finding the causes and a cure for motion sickness could save a great deal of money and promote smoother operations.

This disorder is characterized by a variety of symptoms: the most prevalent are nausea, pallor, sweating, and vomiting. Other possible symptoms include salivation, feeling of warmth, light-headedness, depression or apathy, yawning and drowsiness, belching or flatulence, headache, and occasionally hyperventilation. They are brought on by an unusual or provocative motion stimulus, either real or perceived (2:469).

The leading theory about the mechanism of motion sickness is the sensory conflict theory. It says that when

there is a conflict between different parts of the balance system, motion sickness can result (2:474-481). The balance reflex uses information from several different senses; primarily the vestibular, or inner ear, and the visual system. There is also input from the somatic senses which report the position of body parts and pressure on various surfaces (4:309-310, 323). If the brain perceives these various signals to be in conflict compared to their normal motion cues, motion sickness can result.

There have been two primary avenues of motion sickness treatment: drugs and biofeedback. Each has been somewhat successful in different circumstances.

Drug treatments are the easiest method to apply for alleviating motion sickness; however, drugs have undesirable side effects. In fact, aviators flying solo are prohibited from taking anti-motion sickness drugs (2:491).

Bioofeedback is a promising area of treatment for long-term protection. The School of Aerospace Medicine (SAM) at Brooks MC has had success using skin resistance, muscle tension, and skin temperature as feedback parameters under coriolis stress. Of the aircrew members treated this way about 84%, in one study, were returned to flying status (11:119-121). A problem with biofeedback, however, is identifying physiologic parameters that are good indicators of motion sickness and can also be brought under voluntary control.

Ashton Graybiel and his team took a first step by developing a standard scale for measuring motion sickness discomfort (5). Others have measured skin potential and resistance and correlated them with discomfort (7:141). This provides the basis for selecting parameters for biofeedback treatment, leading to recent AFIT thesis efforts.

In 1983, Capts Earl and Peterson first performed AFIT motion sickness research sponsored by SAM to develop a biofeedback system. Their effort, carried on by Fitzpatrick, Rogers, and Williams in 1984 and by Jarvis and Uyeda in 1985, involved automating data collection and biofeedback parameter presentation so the work formerly performed at SAM could be performed at other bases to reduce cost (3). This effort ultimately proved unsuccessful due to problems with computer equipment. During the course of the experiments, however, the researchers learned a great deal about gathering and analyzing biophysical data and constructed several physiologic sensors to gather a wide range of data (3; 8).

In 1984 Fitzpatrick, Rogers, and Williams suggested building an automated motion sickness prediction model (3:6-1). This has been the thrust of more recent thesis efforts at AFIT (6; 13; 15).

In 1986, Hartle, McPherson, and Miller began integrating the subject's report of discomfort with the other data and correlated the reports with Graybiel's model

(6:53-54, 5). Using automated statistical methods, they were able to establish positive relationships between several physiological parameters and the reported motion sickness index (6:55). This led to development of equations relating several parameters to motion sickness (6:97, 13:59, 15:84).

Summary of Current Knowledge

Several important pathological findings also came out of the 1986 research effort in the areas of galvanic skin response, electroencephalogram, heart rate, skin pallor, respiration, and gastro-intestinal activity.

Galvanic Skin Response. Other work in the field has shown a positive relationship between nociceptive stimuli and increasing skin conductance (17:420,421). This agrees with the AFIT work (13:37).

Gastro-Intestinal Activity. The AFIT researchers computed the power spectral densities of the stomach (EGG) and intestinal (ESG) signals. They found that the signals can be separated on the basis of this type of analysis (6:108).

Electroencephalogram. One of the most exciting discoveries in 1986 was the existence of extremely high amplitude (1 - 5 millivolts), low frequency (0.1 - 0.2 Hertz) waves (1). This previously unknown phenomenon may hold a key to understanding motion sickness. According to Dr. William Czelen (1), EEG responses of these amplitudes but at higher frequencies have been seen during tonic-clonic seizures,

hypercarbia, and asphyxia. It is possible that anticonvulsant drugs may prevent or lessen nausea. This possibility has tremendous implications for aircrew rehabilitation and space flight.

Heart Rate. Although subjects were instructed to halt the experiment just before emesis, one subject inadvertently continued through emesis. He was one of a group of subjects who demonstrated sinus arrest, i.e., the vagal pacemaker signal to the heart was temporarily blocked and the heart rhythm converted to a junctional or ventricular one at a slower rate (35 - 40 beats per minute). When the subject vomited, his heart rate nearly tripled immediately (15:66-67), converting to a sinus tachycardia. All subjects showed increasing heart rate until reporting quite high symptom levels, and then decreasing heart rate until just before emesis. Several later subjects who volunteered to continue to emesis showed the same increase after emesis, although the sinus arrest condition did not necessarily occur.

Skin Pallor. Jarvis and Uyeda found skin pallor patterns linked to motion sickness in 1985 (8:87-88). Hartle, McPherson, and Miller also found pallor changes in 1986, but their data seem to suggest the face flushes while the hands become more pale (13:39). This may have been due to sensor placement problems and unrelated to actual blood flow (1). The problem remained to be resolved at the conclusion of their work.

Respiration. Hartle, McPherson, and Miller found that "the number of breaths increased by approximately 20 percent . . . and the respiratory contribution from the diaphragm increased by about 50 percent" (15:68-69).

Electrosplanchnogram. Hartle, McPherson, and Miller found that the electrointestinogram signal "increased by almost 500 percent" (15:73) and that the electrogastrogram signal "frequency shifts from .12 hz to .06 hz" (15:77).

Problem

The purpose of the present study was to collect and analyze biophysical data relating to motion sickness, test the accuracy and improve upon motion sickness predictors developed by previous AFIT thesis teams, and develop a real-time processor to predict a subject's level of dicomfort.

Assumptions

The assumptions for this research effort are:

1. Motion sickness induced in the laboratory is the same disorder as that found in the real world.
2. The physiological data have a definite correlation to the degree of motion sickness in an individual.
3. Biofeedback techniques developed from a statistical of physiological signals can be used to control or predict motion sickness.

Scope

This is a follow-on research effort to continue the study of motion sickness at AFIT by performing experiments on more subjects and improving methods of data analysis.

This research team experimented with changes in the data analysis equipment. The scope of this research was limited to:

1. Collecting new motion sickness data on 25 volunteers.

2. Standardizing the test procedures.

3. Improving those sensors that proved unreliable in the past.

4. Testing and improving, using second order polynomials, the mathematical models already developed to predict the subjective degree of motion sickness.

5. Integrating new equipment and software into the experimental procedures including:

   a. A differential stethoscope for monitoring gastro-intestinal sounds.

   b. A 16-channel bank of low pass filters to reduce electrical noise.

   c. A 16-channel strip chart recorder.

   d. Data acquisition and analysis software for the Zenith Z-248 computer.

Materials, Equipment, and Software

Materials. Materials include disposable electrodes, alcohol cleaning pads, Beta format video tapes, diskettes, Subject Questionaires and Histories, and 16-channel thermal strip chart paper.

Equipment. The equipment included the following:

1. The powered rotating chair with the following physiological sensors constructed by Dr. Czelen:

   a. electrocardiograph.

   b. two thermistors to measure skin surface temperature.

c. two electronystagmographs to measure eye movement.

d. galvanic skin reflex sensor to measure skin resistivity.

e. two photo-plethysmographs to measure pallor.

f. two electrosplanchnographs to measure gastric and intestinal electrical skin surface potentials.

g. two pneumographs to measure respiration.

h. ballistocardiograph to measure cardiac induced thoracic oscillation.

i. three electroencephalographs to measure brain wave activity.

2. The Zenith Z-248 personnel computer with peripheral units including an 8-channel analog-to-digital converter, and waveform scroller.

3. The Marshall Electronics' Astropulse 90 sphygmomanometer.

4. The SOLTEC model 8K20 series 16-channel strip chart recorder.

5. The Kyowa Dengyo 14-channel Beta tape recorder.

6. The AMPEX FR 1300 16-track FM tape recorder.

7. The 16-channel low pass filter bank constructed by Dr. Czelen.

8. The INTECH Systems' DIF-STET differential stethoscope.

9. The Spiropet pocket Spirometer.

10. The Cyborg Thermal P642 digital thermometer

Software. The software included packages for both data analysis and acquisition. Commercial software packages included DATAQ Instruments' Codas for digitizing and displaying wave forms, MacMillan Software's Asystant for

numerical and statistical analysis, and Metrabyte's C Tool for driving an analog-to-digital converter. The researchers developed software to calculate and report the subject's degree of motion sickness in real time.

Other Support

Dr. William Czelen (M.D., B.S.E.E.) provided necessary medical expertise for screening volunteers. In addition, he observed all experiments to ensure the physical well-being of all subjects. Finally, he provided technical support through circuit design.

II. Experimental and Procedural Changes

This experiment was a continuation of work performed in previous years by Hartle, McPherson, and Miller, by Jarvis and Uyeda, and others (3; 6; 8; 13; 15). The experimental procedure consisted of spinning a volunteer subject about his z-axis in a powered rotating chair at a constant, controlled speed, and gathering up to 21 channels of physiological data as the subject tilted his head out of the plane of rotation to elicit a motion sickness response. The subject reported his discomfort by a numerical score from 1 to 10, where 1 meant the subject was asymptomatic and 10 meant emesis was imminent. The data were then analyzed by appropriate statistical techniques to determine relationships between the parameters and finally, a computer model was developed, to compute in real time an indication of the subject's numerical score. More detailed descriptions are available in the previous theses and in the research protocol in the appendix of the thesis by Captain Gaudreault. Following are the major changes from the previous experiments.

Environment

The motion chair is presently installed in a unair-conditioned enviroment. When experiments were conducted with high ambient temperatures, thermal sweating regularly loosened the electrodes and sensors from the subject's skin. Partitions were set up surrounding the motion chair and a

parachute was suspended above it to enclose the area. A portable room air conditioner was installed to help control the environment immediately around the chair. In this way, it was sometimes possible to maintain the temperature in the ideal 22 to 24 degree Centigrade (71 to 75 degree Fahrenheit) range (17:418) when the ambient air temperature would otherwise have prevented experimental runs.

Procedures

The order of preparation of the subject was changed from the procedures the previous thesis team used to minimize the amount of time the electrodes were attached to the subjects' skin. The physical exam was done first, then the plethysmographs were calibrated. The body electrodes and sensors were attached before the subject mounted the chair, and the leads to the sensor electronics were connected afterwards. The pneumographs were then calibrated, and the facial electrodes and sensors were attached. Finally, the eyes were taped closed and the subdermal EEG electrodes were inserted. This method minimized sensor losses caused by perspiration loosening the adhesive.

Sensors

EEG. The previous thesis team discovered extremely low frequency, high amplitude, EEG signals associated with motion sickness. To eliminate the possibility that these signals were a sweat induced artifact, subdermal electrodes are now used.

Skin Pallor. The plethysmographs used before had a red LED and a phototransistor to measure the change in skin reflectivity due to flushing. However, flushed skin looks darker because the hemoglobin absorbs shorter wavelengths of light and reflects only red. Thus, the reflectivity of skin in red light changes very little, but the reflectivity in other colors (like green) changes dramatically. The LEDs have therefore been changed to green to take advantage of this effect. Also a second phototransistor, covered by opaque paint and connected to a balancing circuit, has been added to each sensor for temperature compensation. Both sensors were moved to the sub-orbital area of the face, one on each side. This area shows significant pallor change and has no large blood vessels. Finally, the adhesive used to hold the sensors in place irritated the skin of many subjects, masking any skin color change due to blood flow change. The plethysmographs are now held in place by taping over the top of the sensor. Because of these problems, the skin pallor data gathered before these changes have not been used in this study.

Gastro-Intestinal Measurements. A phonosplanchnogram has been added to the data collected. The sensor is a battery powered, self contained stethoscope with differential inputs. It is attached to the central abdominal region and records bowel sound activity. The output is recorded with the FM data recorder.

Recording and Processing Equipment

The previously used Bushmark strip chart recorders have been replaced by a Soltec model 8k26 16-channel chart recorder. It uses heat sensitive paper rather than ink, and is much easier to operate than the old recorders.

A Zenith 248 computer with an 8-channel analog-to-digital converter board was used to digitize data and analyze it. The computer was also used to analyze the data in real time and could be used to provide biofeedback information.

The previous researchers had problems with 60 Hz hum in their data. To solve the problem, a 16-channel active filter bank has been added to the data circuit. It uses two pole low pass active filters with 6dB points set at 30 Hz. These filters eliminated the 60 Hz noise from the recorded data.

III. Analysis of Previous Theses

Motion sickness has been studied at AFIT since 1983. The studies completed for the year's 1983-1985 are summarized in the 1986 theses of Hartle, McPherson, and Miller (3; 13; 15). This chapter will describe the accomplishments of the 1986 team, analyze their results and describe changes of direction made by the 1987 thesis team.

Accomplishments

The 1986 thesis team made several significant contributions to the study of motion sickness. Each of these will be discussed on the following pages. These accomplishments are:

1. The team set up the motion sickness chair in building 640.
2. The team developed and followed a "standard" experimental procedure.
3. The team improved the physiological monitoring circuitry, data recording equipment and techniques.
4. The team gathered physiological data from a pool of 20 volunteers for data analysis
5. The team performed in depth statistical analysis on the gathered physiological data and derived linear equations to determine a subjects level of motion sickness.

Chair Move. The 1986 team was involved in moving the chair to building 640. This move was necessary because it allowed the researchers and possible subjects to be near the equipment and also put the chair into a room scheduled for air conditioning.

The move allowed the team to find several pieces of malfunctioning mechanical and electrical equipment on the chair. This was significant because the chair was then repaired in a timely manner before a major malfunction occured which might possibly have resulted in physical injury to volunteers, or serious damage to the chair.

Procedures. The 1986 thesis team set up standard experimental procedures. This allowed all experiments to be run under the same conditons. Previous teams experimented to find an optimum procedure, but the 1986 team determined which chair speeds and methods of head movements would be best, for this specific research problem, and developed a standard procedure using these. Because experiments were standardized, the data could be compared without concern for differences caused by changes in procedures.

Equipment and Techniques. The 1986 team set up the Beta recorder for data collection, designed and integrated circuitry to allow standardized calibration of actual real time readouts of data instead of measuring only a change from baseline. This enables researchers to relate actual data as collected to the baseline data.

Statistical Analysis and Derived Equations. Most researchers have reported increased pallor, stomach awareness, sweating and other physiological changes while a subject begins to get sick, but few researchers have recorded data showing quantifiable results. The 1986 team recorded data and derived three linear equations relating a

subject's physiological signals with how he feels subjectively. The derived equations are a very important step toward the prediction of impending sickness as well as the control or elimination of this sickness.

As stated previously, the 1986 thesis team of Hartle, McPherson, and Miller derived three equations to predict a subject's level of motion sickness. These equations are:

From Hartle (6:97):

$$Y = 595.55 - 0.2268(thor) + 0.1540(fing) - 0.6581(GSR) + 2.8497(heart) + 0.2624(temp) - 100.8295(breaths) \quad (1)$$

where

Y	=	predicted level of motion sickness
thor	=	thoracic volume (CC)
fing	=	finger pallor (percent flush)
GSR	=	Galvanic Skin Response (K ohms)
heart	=	heart rate
temp	=	temperature (degrees Fahrenheit)
breaths	=	number of breaths per 10 sec interval

From McPherson (13:59):

$$Y = 0.9358 + 0.0095(Thoracic) + 0.1465(Finger) - 0.0004(GSR) + 0.0334(EKG) + 0.2449(Temp) + 0.3696(Breath) \quad (2)$$

where

Y	=	predicted level of motion sickness
Thoracic	=	Thoracic Volume
Finger	=	Finger Pallor
GSR	=	Galvanic Skin Response (K ohms)
EKG	=	Heart Rate
Temp	=	Temperature
Breaths	=	Breaths

The units used by McPherson are not listed and this author was unable to determine reasonable units. It appears McPherson used the absolute value of the difference between a measured value and a baseline value, but it is unclear as to whether averaging of the measured data took place, or if some other method was used.

And from Miller (15:84):

$$|Y| = -69.3938 + 0.0634(t) - 0.3512(f1) + 0.4514(f2) - 0.00000627(g) - 0.0179(e1) - 0.2006(e2) + 0.5518(e3) \quad (3)$$

where

Y = level of motion sickness to be predicted
t = thoracic respiration (CC)
f1 = finger pallor (per cent flush)
f2 = facial pallor (per cent flush)
g = galvanic skin response (K ohms)
e1 = eig
e2 = egg
e3 = ekg (pulses per minute)

Miller also did not list the units used for his data, but except for EIG and EGG the units may be readily determined by looking at the data in his thesis.

The best test of a model (equation) is by evaluation with an actual input. Each of last year's theses contain the data, actual or processed, obtained from the pool of volunteers run by the 1986 thesis team. As the data from each thesis is placed into its corresponding equation, a motion sickness level may be calculated. The tables on the following pages represent the output of each equation using

the data, which was used to produce the equation, as an input. The values listed in Table 1 were produced using Miller's equation, along with the "interpolated mean values" (14:59) found in his thesis, and also by using the same equation and all but the GSR data. The values in Table 2 were produced using Hartle's equation along with the "mean values" (3:95) found in his thesis. The values in Table 3 were produced using McPherson's equation and the "mean values for individual changes" (12:60) found in his thesis. A discussion will follow each table.

Table 1

Calculated Values For Level of Motion Sickness
Using Miller's Equation With
Interpolated Mean Values (15)

REPORTED LEVEL	CALCULATED LEVEL	CALCULATED LEVEL WITHOUT GSR
1	0.992	0.996
2	1.992	1.996
3	2.992	2.996
4	3.992	3.997
5	4.993	4.997
6	5.993	5.997
7	6.993	6.997
8	7.993	7.997
9	8.993	8.996
10	9.992	9.996

Table 1 indicates that a slightly better estimation of a person's level of motion sickness is obtained by omitting the GSR data. This would seem to indicate that either GSR

is not a good indicator of motion sickness, or that the GSR data collected by the 1986 team were in error. By examining the 1986 GSR data, it is seen that for some subjects the skin resistance appears to remain the same, or in some instances to increase, while a subject is getting sick and/or sweating. This alone strongly suggests that the GSR data collected were not valid.

It should also be noted that the data in Miller's thesis did not require the use of the absolute value sign on the left hand side of his equation. It is unclear as to whether the absolute value sign was derived by computer or inserted later by Miller, but for this set of data the absolute value sign was extraneous.

Table 2

Calculated Values For Level of Motion Sickness Using Hartle's Equation With Mean Values (3)

REPORTED LEVEL	CALCULATED LEVEL
1	0.972
2	1.972
3	2.971
4	3.972
5	5.127
6	5.981
7	7.115
8	7.953
9	9.087
10	9.974

The data in Table 2 appears to indicate that Hartle's equation is not as accurate as Miller's. This is because Miller linearly interpolated the mean values of the data, which would tend to produce more linear curve fits even though the data may or may not be accurate. As Hartle did not interpolate the mean values of the data, his data more closely approximates the true data. For this reason, it would appear that Hartle's equation would serve as a good motion sickness indicator. Unfortunately, this is not the case. An explanation of why will follow the discussion of McPherson's equation.

Table 3

Calculated Values for Level of Motion Sickness Using McPherson's Equation and Absolute Value of the Change in Value of the Physiological Signals (13)

Subject	Interpolated Level		
	2	6	9
	Calculated Level		
2	2.846	5.028	8.619
3	2.920	4.696	10.310
4	4.833	4.074	9.796
5	3.741	4.196	7.687
6	3.289	6.511	7.117
7	2.724	5.936	8.100
8	5.539	5.713	8.801
9	2.913	4.760	6.790
10	2.756	6.309	11.850
11	2.838	5.542	7.472
12	3.066	3.459	6.938
average	3.406	5.111	8.498

One would expect that an equation which uses actual values, or the amount of change in actual values, would produce a better estimator than equations which use mean values or interpolated mean values. The results shown in Table 3 do not support this idea however. The discrepancy here is that while McPherson used values which more closely represented the true values than Hartle or Miller, he did not use the subject's actual report of symptom level, But rather, he used a average symptom level.

The problem with the estimators is not that the data measured are not related to motion sickness, but that the relationship is not a linear one. The equations produced by the 1986 team show that there is a relationship between the physiological signals they were measuring and the level of motion sickness reported by a volunteer. The problem left for the 1987 thesis team, and future researchers, is to improve upon the 1986 work in the development of a motion sickness indicator, a real-time processor, and perhaps a motion sickness predictor.

IV. Data Analysis

This chapter begins with a description of the regression technique used to perform statistical analysis on the data collected during experimentation. This is followed by a discussion on methods to determine the Coriolis Sickness Susceptibility Index (CSSI) score for an individual. The physiological data collected are then presented, along with the application of the data to the motion sickness indicator, developed by this thesis team.

Regression

The 1986 thesis team performed linear regression on the data collected during their experiments. There are several regression techniques other than linear which may be used in the research on motion sickness. Some of these regression techniques are: polynomial, logarithmic, and exponential regression. As mentioned in Chapter I, this thesis team limited its regression technique to polynomial regression, and in particular first and second order polynomials.

Polynomial regression is an extension of linear regression. Instead of trying to find a first degree polynomial (linear) equation which relates the dependent variable to the independent variable, an attempt is made to fit the dependent variable to the independent variable through the use of higher order polynomials. The difficulty with polynomial regression is to determine what order

polynomial equation best fits a set of data. To find what order of approximation best fit the data collected and motion sickness regression equations were derived for both first and second order fits using a statistical software package. If the first order equation produced a better fit than the second order equation, then the first order equation was used, otherwise the second order equation was used.

Coriolis Sickness Susceptibility Index (CSSI) Tests

An individual has a CSSI level which can be determined by susceptibility tests (13:7). The most desirable test would require a minimal amount of data acquisition time, equipment, and laboratory personnel. By devising a CSSI test which meets these criteria a group of prospective aircrew members may be tested to determine their levels of susceptibility. Once the CSSI level is determined for each individual in a group, the group may be subdivided into two subgroups, those with low CSSI levels (susceptible to motion sickness) and those with a high CSSI levels (not susceptible to motion sickness). Those determined to be susceptible to motion sickness would then go through motion sickness training in an attempt to change their CSSI level to a higher score. It might be possible to derive a test which would determine which persons can not be trained to avoid motion sickness.

Several methods have been used to determine a person's CSSI level. These methods have ranged from the simple measurement of various physiological signals to performing extensive collection of data through experiments requiring costly test equipment, circuitry, and recording equipment, hours of experimental and data analysis time, and several researchers.

This team has used three methods to approximate a person's susceptibility level. These three methods were: a balance test, a fully instrumented data acquisition experiment, and a short uninstrumented test. These three methods and their usefullness are described below.

Balance Test. It has been considered possible to characterize a person's CSSI level by testing his sense of balance. It was believed that a person with a good sense of balance would get motion sick more easily than a person with a poor sense of balance because a person with a good sense of balance could sense changes in body position better than a person with a poor sense of balance (1).

A balance test was used to attempt to predict a person's CSSI level. Each subject was asked to perform balance tests by first balancing on both feet, one in front of the other, heel to toe, first with the eyes open, then closed. Next the subject was asked to balance on one foot, first with the eyes open, and then closed. The later test was repeated with the subject standing on the other foot. Subjects were rated as having a good sense of balance, a fair

sense of balance, or a poor sense of balance based on the length of time they were able to maintain their balance (20 seconds or more, 10-20 seconds, or less than 10 seconds). The subjects were run in the chair, using the susceptibility test procedure and protocol listed in the thesis by Gaudreault, and the subject's sense of balance was compared with his level of susceptibility, length of experiment. The results of these tests are shown in Figure 1.

Figure 1 shows the length of time to reach a symptom level for the longest and shortest complete susceptibility tests for those subjects with good balance as well as the susceptibility tests for three subjects with poor balance. Of the 14 subjects with good balance, four subjects were still reporting a symptom level of "3" after 300 seconds of rotation. This suggests that these four subjects are unsusceptible to motion sickness.

Some subjects with a good sense of balance were determined to be susceptible to motion sickness while others were not susceptible. Some subject's with a poor sense of balance were not susceptible to motion sickness while others were. Averaging the "time to reach sickness level" between subjects with good balance, and likewise for those with poor balance, suggests that those persons with a poor sense of balance are less suceptible to motion sickness than those with a good sense of balance (10). At this preliminary stage, a person's CSSI level can not be determined by balance tests alone.

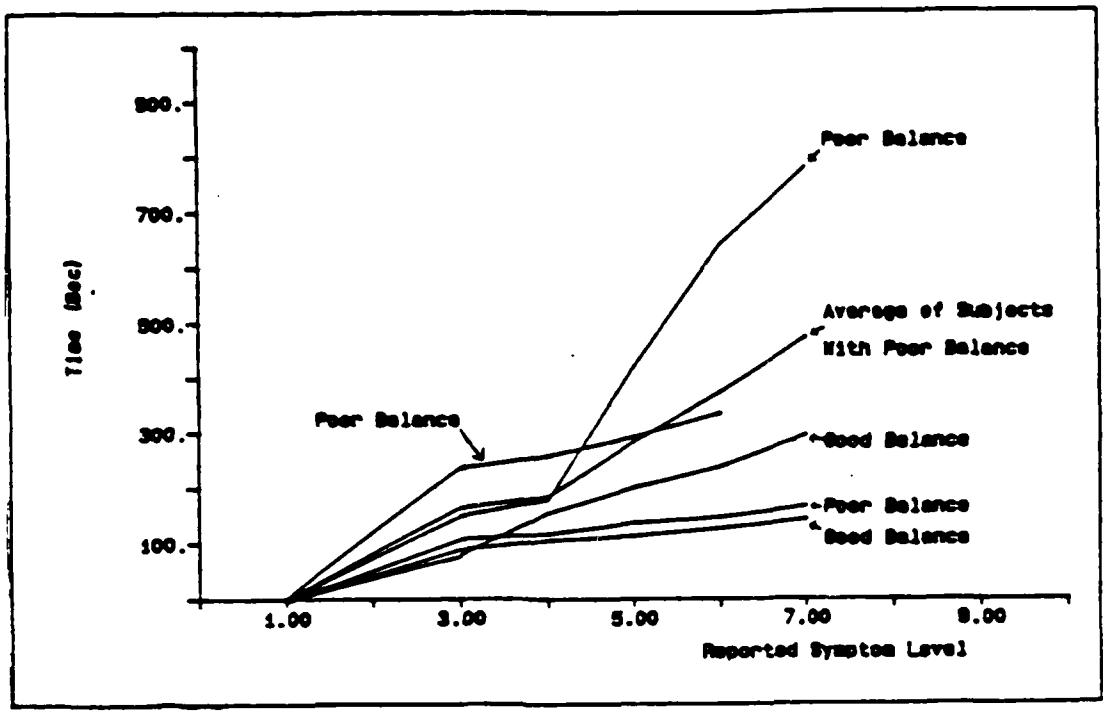


Figure 1. Time to Reach Symptom Level for Subjects with Different Balancing Abilities

Fully Instrumented Data Acquisition Experiment. This method of CSSI testing involved the collection of 22 channels of data (including subjective reports on the subject's feeling of sickness). Data collected were used in the development of the motion sickness indicator described in the thesis by Captain Edward Fix. This form of CSSI test has two advantages and three disadvantages over the short uninstrumented test (AFIT Susceptibility Test) described later.

The advantages are:

1. Since the experiment has an endpoint at or near emesis a more accurate estimate of a person's CSSI level can be determined.

2. With instrumentation attached, data may be collected for use in determining a motion sickness indicator and/or predictor.

The disadvantages are:

1. As the end point of this experiment is at or near emesis, each experiment requires the presence of a physician as well as the personnel monitoring the recording and control equipment.

2. The calibration and control of equipment and recording devices extend each experiment to two or three hours. During this time three to four people must be in attendence. The number of actual experiments which can be run in a given time period is significantly reduced because of the amount of time required to perform an experiment and the schedules of the experimenters and the subjects. This team never ran more than one full length experiment in a given day.

3. The materials and equipment used for data collection are numerous and expensive. In addition, down-time can be expected while waiting for supplies.

Table 4 shows the relationship between the length of the fully instrumented runs and a person's level of susceptibility. Since this thesis team used the same protocol as the 1986 thesis team the data from the 1986 experiments are included.

Due to the length of this test, it is not practical as a susceptibility test. While it is extremely effective in indicating which persons are or are not susceptible to motion sickness, it could not be used to test large groups of persons, 100 or more, in a short period of time.

AFIT Susceptibility Test. Researchers have attempted to reduce a person's CSSI level to a single number. Miller and Graybiel found that a person's CSSI level can be

Table 4

Length of Time Required to Reach Specific Level During Full Experiment

Subject	Chair Velocity (RPM)	Time to Reach Level (sec)							
		Level							
		3	4	5	6	7	8	9	10
1	14	110	120	180	---	210	---	---	---
2	18	160	250	260	290	300	---	---	---
3	18	60	80	100	120	130	200	---	---
4	14	90	---	---	110	---	---	130	140
5	18	100	120	140	180	190	270	---	---
6	10	80	---	90	110	140	150	160	320
7	14	80	110	130	150	---	170	---	190
8	14	100	125	130	---	150	170	190	230
9	14	80	---	95	105	---	120	---	140
10	14	15	50	---	70	80	85	90	110
11	14	100	---	120	130	---	150	160	190
12	14	180	210	260	280	---	---	---	---
13	12	110	190	210	250	270	310	---	---
14	14	70	---	---	100	190	230	280	310
15	14	160	---	---	---	300	---	320	---
16	14	---	120	---	---	---	159	180	200
17	14	---	---	260	280	---	---	---	---
18	14	---	190	---	---	220	---	240	---
19	14	130	150	---	180	190	210	240	---
20	14	---	---	150	---	---	240	260	270
21	14	70	---	80	160	200	220	240	290
22	14	---	---	---	80	---	120	160	---
23	14	230	320	---	330	340	370	390	---
24	14	100	130	140	150	160	170	230	250
25	14	130	170	---	180	---	---	210	---
26	14	130	---	150	---	190	---	210	270
27	14	110	180	---	220	230	240	260	280
28	14	---	---	140	---	---	150	170	190
29	14	---	250	---	280	---	290	330	---

determined by multipying the total number of head tilts (N) by a number less than 0.6, called the E factor, which is related to the rotational velocity of a rotating chair by Eq (4) (14:10):

$$CSSI = E * N \qquad (4)$$

Miller's data did not include any subject with a CSSI score of 0, and the upper limit was imposed by considering data from subjects which did not get sick within 166 head movements as invalid. The CSSI level of an individual, using Miller's method (described below), can take on values between 0 and 100. Those with a low CSSI level are more susceptible to motion sickness than those with a higher CSSI level. Miller stated that the end point of each experiment should be common for subjects when trying to determine their CSSI scores. Miller and Graybiel chose the onset of Malaise III (M III) as their end point for experimentation because:

> The predetermined endpoint for each subject was severe malaise (M III). The desired level of motion sickness imposed upon each subject was such that this level of malaise was approached rather gradually so that the observer could readily identify and register symptoms in sequence as they were manifested, but more importantly, so that the subject was not over-stimulated, particulary to the point of extreme nausea or vomiting (frank sickness) (14:8).

As Miller and Graybiel's work is generally accepted by researchers of motion sickness, it was decided to see if any connection could be made between Graybiel's malaise levels and our subject reports. In addition, if subject reports are related to Malaise levels, it was decided to find the stress level of the head movements under the AFIT experimental protocol in comparison to Graybiel's stress factors.

By observing a person's actions, sweating, and pallor, and listening to their reports on their physical well-being and level of sickness reports, it was determined that the

AFIT and Graybiel levels of sickness are similar as listed in Table 5.

This thesis team began using susceptibility tests, short uninstrumented experiments, to determine which subjects were suitable for our full length experiments and to determine at what rotational velocities each experiment should be run. This was because we only wanted data from susceptible persons (1), we wanted experiments to last more than 4 minutes so that a person's physiological signals were more correlated with their sickness level, and we didn't want extremely long experiments which would result in protracted subject discomfort.

The susceptibility test (CSSI test) was very effective in predicting the velocities to use for the full length experiments. By spinning a subject during the CSSI test until he reached a 7, Malaise III, predictions could then be made as to what rotational velocity was required to have the subject reach a 7 after 25 head movements, or after some other number of head movements (by using Miller and Graybiel's table of stress values for different rotational velocities, shown in Table 6 and Figure 2). In addition, by using the stress factors for the different rotational velocities, predictions could be made concerning the number of head movements required to make a subject reach a symptom level less than a 7, see Table 7. This is accomplished by multiplying the number of head movements required to reach a symptom level by the stress level for that velocity, and

TABLE 5

Comparison Between AFIT Levels and Graybiel Levels

AFIT LEVEL	GRAYBIEL LEVEL
1	Control
2	M I
3-4	M IIB
5-6	M IIA
7-9	M III
10	Frank Sickness

Table 6 (14:10)

Stress Factor per Head Tilt for Given Rotational Velocities

Stress Level	Rotational Velocity (RPM)
0.60	30.0
0.43	25.0
0.28	20.0
0.165	15.0
0.118	12.5
0.078	10.0
0.046	7.5
0.021	5.0
0.006	2.5

then dividing the result by the stress level for the new velocity. The data indicate that the length of an experiment can be controlled to within a few head movements.

Protocol Comparison. Up to this point no comparisons have been made between Graybiel's protocol and the AFIT protocol. The method of head movements, pause between head movements, and direction of head movements in the two protocols are different. The method of performing

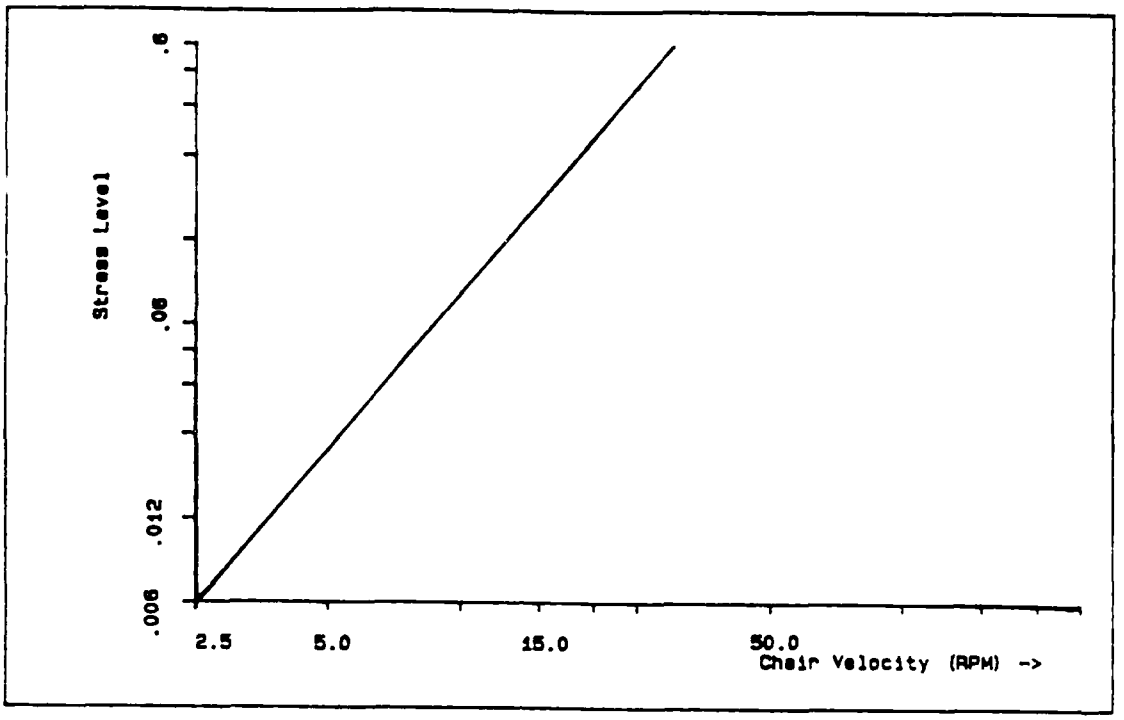


Figure 2. Stress Levels for Individual Head Movements for Different Rotational Velocities using Graybiel's Protocol (14:10)

head movements under the AFIT protocol are listed in the thesis by Captain Pierre Gaudreault. The protocol used by Graybiel is as follows (14:9):

1. Head movements are performed in the following order:

   front, upright, pause; right, upright,pause; back, upright, pause; left, upright, pause; front, upright,rest.

2. Each pause lasts for 1 second.

3. Each rest period lasts 20 seconds, followed by another set of head movements until the subject either reaches a Malaise III, or has performed 166 head movements.

4. Each set of head movements contains 5 head movements with all but the upward movements counting as head movements.

Table 7

Comparison Between Runs at Different Velocities

$$\text{New \# Movements} = (E1/E2)*(\text{Old \# Movements}) \qquad (5)$$

Where:

E1 = Stress Factor at first rotational velocity
E2 = Stress Factor at second rotational velocity

Subject	Run #	RPM	# Head Tilts to reach symptom 3	4	5	6	7	Actual/Expected
1	1	14	2	3	3	stopped		
1	2	10	4	5	5			Expected
1	2	10	3	-	4	6	9	Actual
2	1	14	-	6	9	15	17	
2	2	12	-	8	12	20	22	Expected
2	2	12	-	14	16	20	22	Actual
3	1	14	9	19	19	27	32+	
3	2	18	6	12	12	17	20+	Expected
3	2	18	8	12	14	18	25	Actual
4	1	14	12	15	17	25	26+	
4	2	18	8	9	11	16	16+	Expected
4	2	18	7	12	15	17	20	Actual

Note: Subject #1 stopped after three head movements because she was starting to get very sick and subject #3 stopped after 32 head movements but never reported being a "7".

Subjects were run using both the AFIT and the Graybiel protocols. This allowed a comparison to be made as to how long it took a subject to reach Malaise III/symptom level 7 under the two protocols. The data are shown in Table 8.

Table 8.

Number of Head Movements Required to Reach Malaise III Under AFIT and Graybiel Protocol

Subject	Protocol Used	
	AFIT	GRAYBIEL
1	9	18
2	19	15

The limited data do not allow a precise calculation concerning how much more effective, if at all, the AFIT protocol is than the Graybiel protocol. As the Graybiel protocol does not count upward head movements, as head movements, it is believed that the AFIT protocol is more effective in inducing motion sickness as the Graybiel protocol.

Usefulness of the CSSI Test. The susceptibility test has several potential uses. The first use of the CSSI Test is to act as a method of screening out unsusceptible persons from the full run data pool. Another area in which the CSSI test proves useful is in the determination of the optimum rotational velocity for the full run. The ultimate use of the CSSI test is as a susceptibility test to determine who might need to undergo motion sickness training prior to flight training. At this time this test can not be used as a eliminator for those applying for flight school because no data have been collected indicating what CSSI level is unacceptable for a flyer. As an example two of our subjects underwent flight training,

one has been a successful pilot, and the other washed out of flight school because of motion sickness, after going through motion sickness training at Sheppard AFB. Their respective CSSI levels are 5.76 and 1.30 respectively, but there is no indication that a different individual with a CSSI level of 1.3, or less, could not be trained to control motion sickness, and then be acceptable as a student pilot.

Physiological Data Analysis

The remainder of this chapter will cover an analysis of selected physiological data. The signals discussed are GSR, Temperature, Respiration, Electrosplanchnogram, Electronystagnogram, Electroencephalogram, and Pallor. The indicator equation is derived, using the first five signals listed, in the thesis by Captain Edward Fix.

Galvanic Skin Response (GSR). Galvanic skin response "is a measure of the electrical conductivity of the skin" (6:67). While GSR was measured as resistance, in ohms, it was recorded on the strip chart and Beta recorders as a voltage, where each recorded voltage level corresponded to a specific resistance level. Also recorded were reference voltages indicating preset resistances, between 0 and 1.6 Megohms to provide calibration during data analysis. As a subject progressed from little, or no, feelings of anxiety towards frank sickness his skin resistance dropped dramatically, as shown in Figure 3.

Every subject tested demonstrated this trend in GSR readings. In addition, as subjects began to feel better,

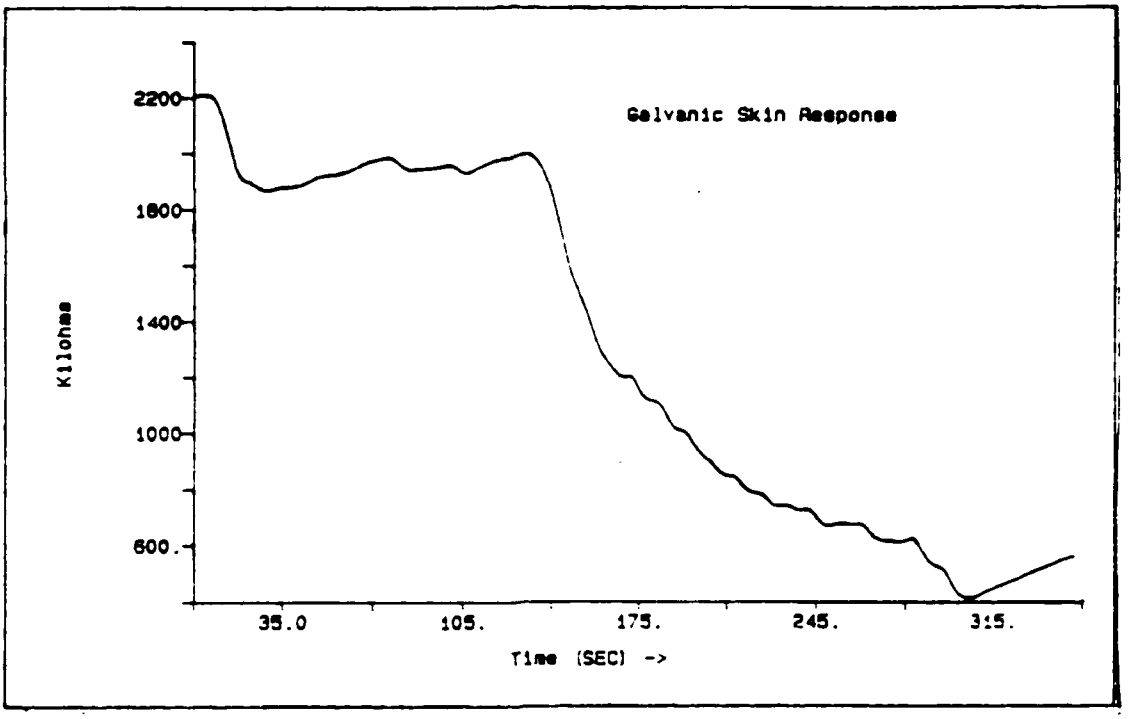


Figure 3. Skin Resistance as a Function of Time During Experimental Run

their skin resistance began to increase immediately, sometimes almost fully returning to its original value within a few minutes.

Since no two subjects had the same original baseline skin resistance, it was determined that the actual resistance level and the change in resistance levels were not good indicators of motion sickness even though subject skin resistance dropped. It was determined that a different indicator was necessary to estimate a persons subjective level of motion sickness.

It was found that motion sickness and the percent change in resistance from baseline were closely related. A number between "0" and "1" used in curve fitting, and shown

in Figure 4, was derived by the equation:

$$X = 1 - (\text{present resistance})/(\text{baseline resistance}) \quad (5)$$

Temperature. Peripheral temperature was measured on the subject's right hand between the third and fourth digits and was recorded on both the strip chart and Beta recorders. Facial temperature was measured on the subject's cheek and was manually recorded on the strip chart recorder. Facial temperature was not used in the development of the motion sickness indicator because it was not recorded on the Beta recorder and hence could not tested in the real-time processor.

As reported last year, and shown in Figures 5 and 6, subject temperature did not change significantly. As with GSR, because each subject had a different baseline temperature motion sickness could not be related to a subjects temperature, but rather to the change in temperature.

Respiration. Respiration was measured in two areas: thoracic respiration and abdominal respiration. Thoracic respiration was used in the motion sickness indicator construction. Abdominal respiration data was not used in the construction of the motion sickness indicator because of the difficulty of subtracting out the thoracic component which is detected by the abdominal sensor due to placement of the strain gauges. The strain gauges for abdominal respiration are placed near the diaphragm because of the placement of ESG and EKG electrodes.

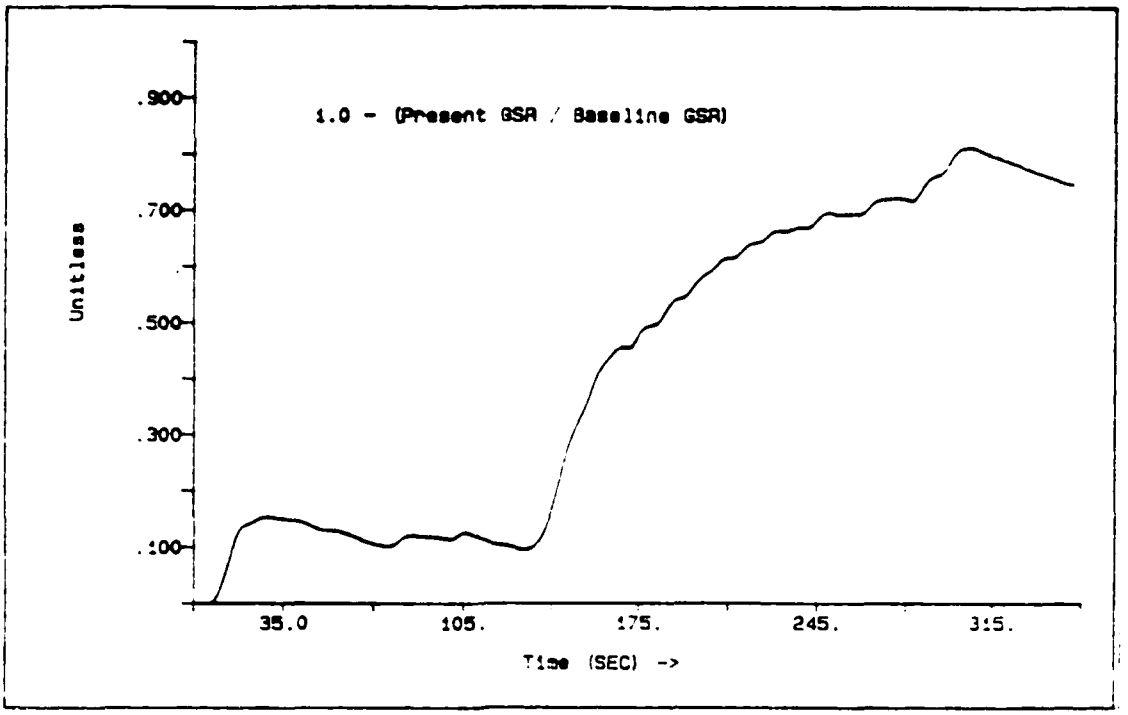


Figure 4. 1 - Normalized Skin Resistance vs. Time During Experiment

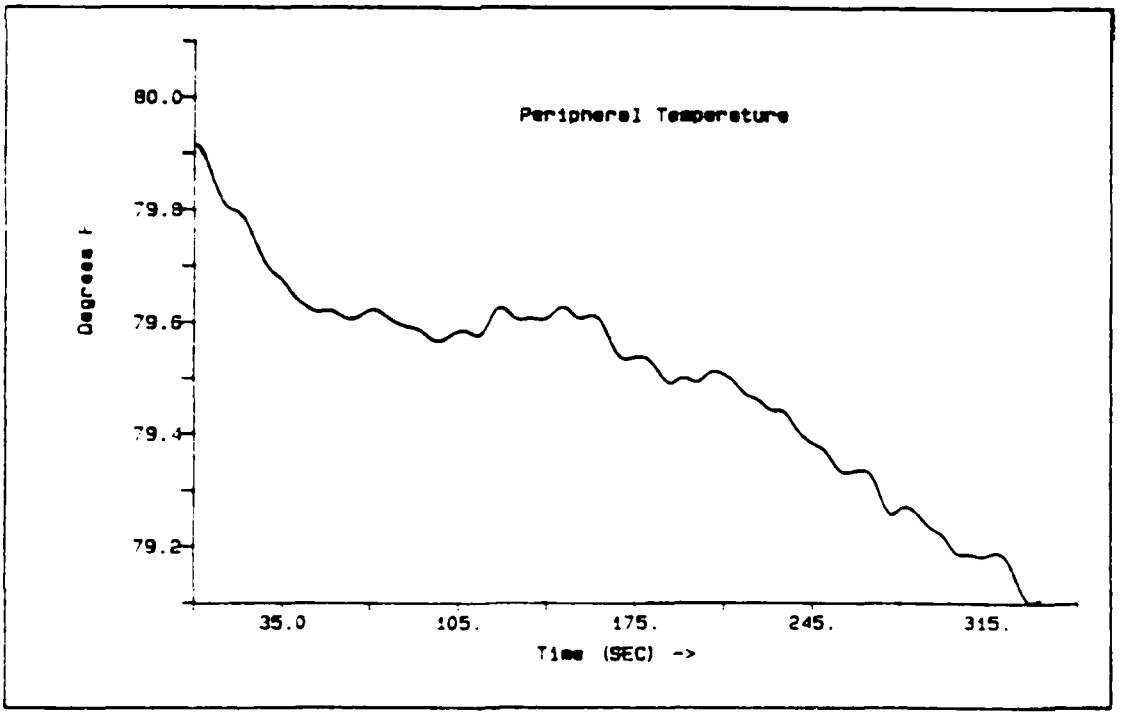


Figure 5. Subject Temperature (Peripheral) vs. Time During Experiment

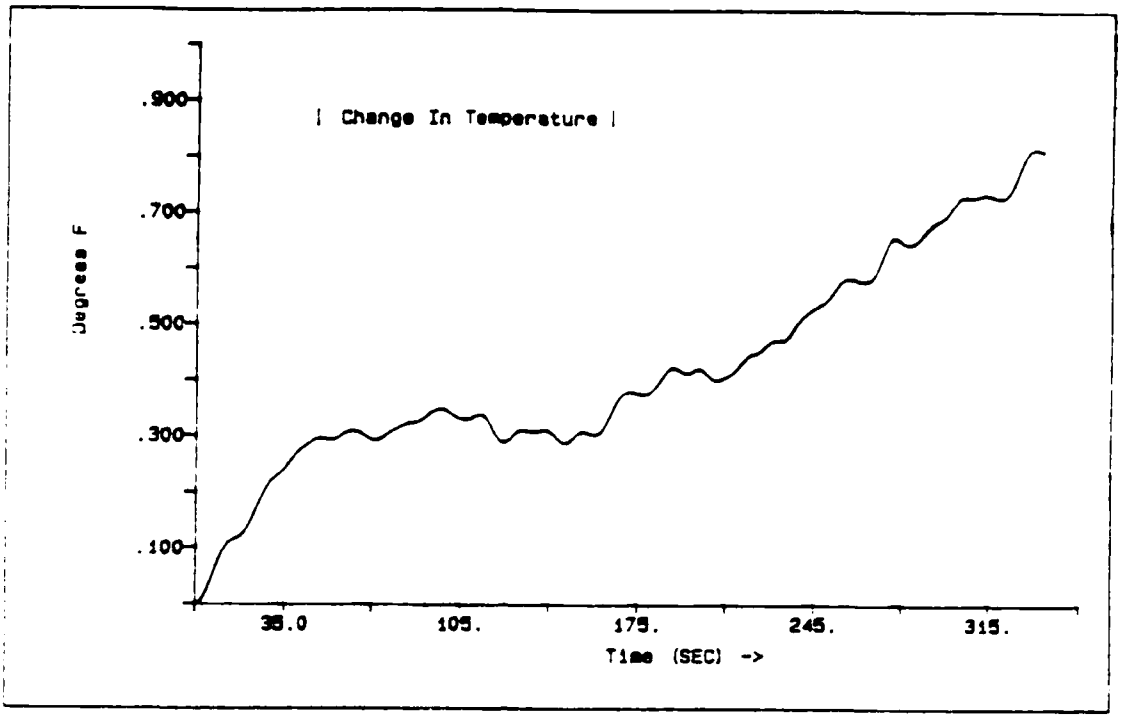


Figure 6. Absolute Value of Change in Temperature During Experiment

Many researchers claim that there is little change in respiration due to the fact that the respiration rate remains fairly constant over the duration of the experiment (1). While our data confirms that the frequency of breaths does not change, see Gaudreault, it does indicate that the volume of each breath increases significantly, as shown in Figure 7.

Figure 7 shows that as a subject gets motion sick he begins to take deeper breaths, and in most cases doubles his intake per minute, as compared to baseline, even though his number of breaths per minute remains virtually the same. The data indicates that a person begins to hyperventilate as he gets sick resulting in a change in the

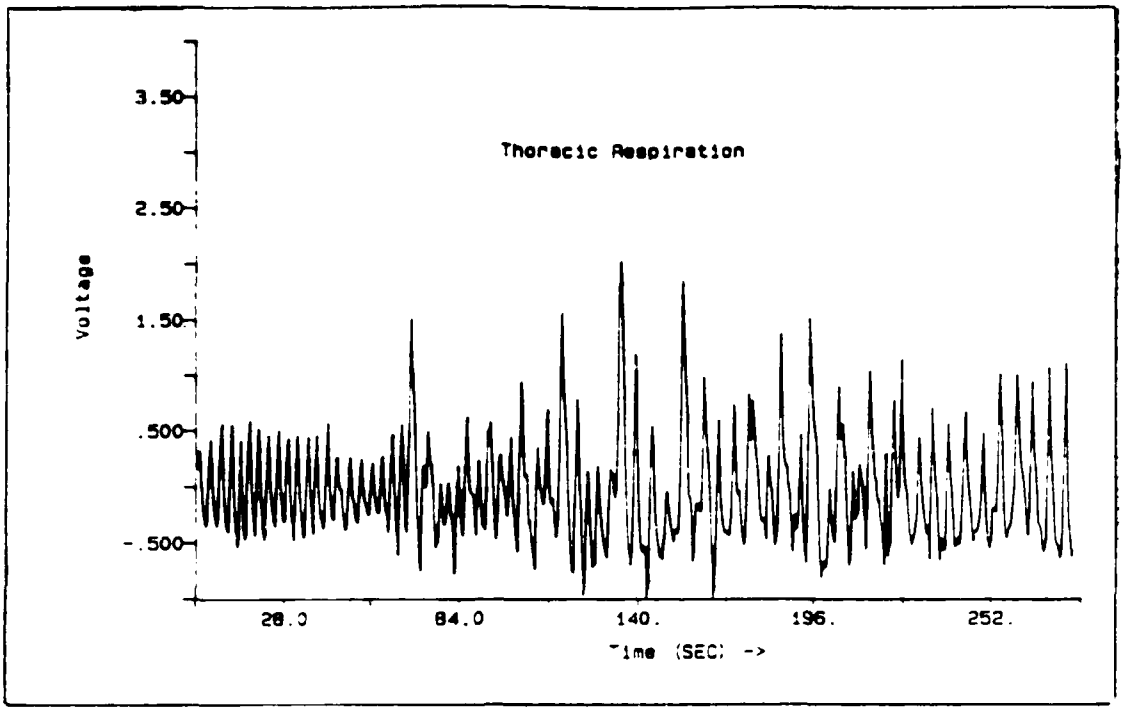


Figure 7. Thoracic Respiration vs. Time

pH level of the blood (1). More information on the frequency and amplitudes of the breaths of subjects may be found in the thesis by Captain Gaudreault.

While Figure 7 shows an increase in the volume of air actually breathed, this data is of little use in a real-time processor. For this reason it was decided to calculate the RMS level of the breaths. The RMS calculation is made by convolving the squared sampled data values with a rectangular function (Rect function), of 20 seconds duration and normalized so that the area under the Rect function is equal to 1.0, then taking the square root of the convolved data. Figure 8 shows the result of processing the data of Figure 7 by this method. While this

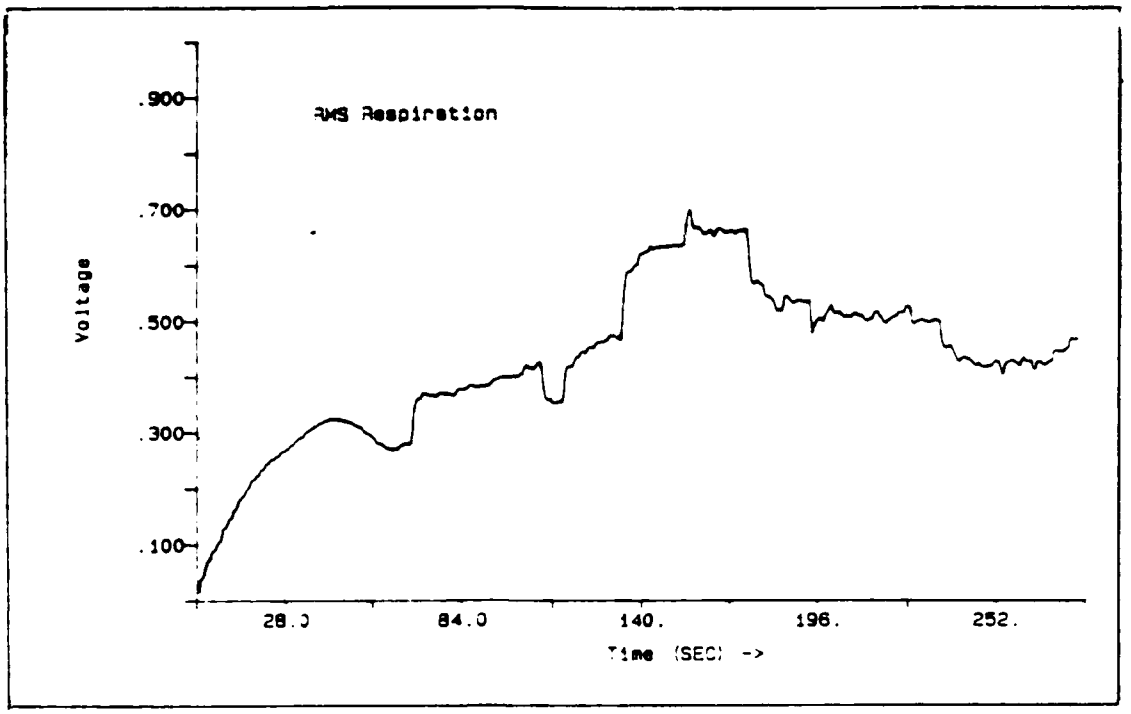


Figure 8. RMS Thoracic Respiration vs. Time

technique produces a much smoother curve, the RMS level itself is still not a very good indicator of motion sickness, for the same reasons mentioned for GSR and temperature. Dividing the "present RMS" level by the "baseline RMS" level generates a curve, shown in Figure 9, which represents the increase in breath volume taken in by a subject while he undergoes motion sickness. Motion sickness was well related to this data.

Electrosplanchnogram (ESG). As with respiration the amplitude of the ESG signals increased significantly as shown in Figure 10. As with respiration, RMS amplitude levels, but not divided by RMS baseline in the motion

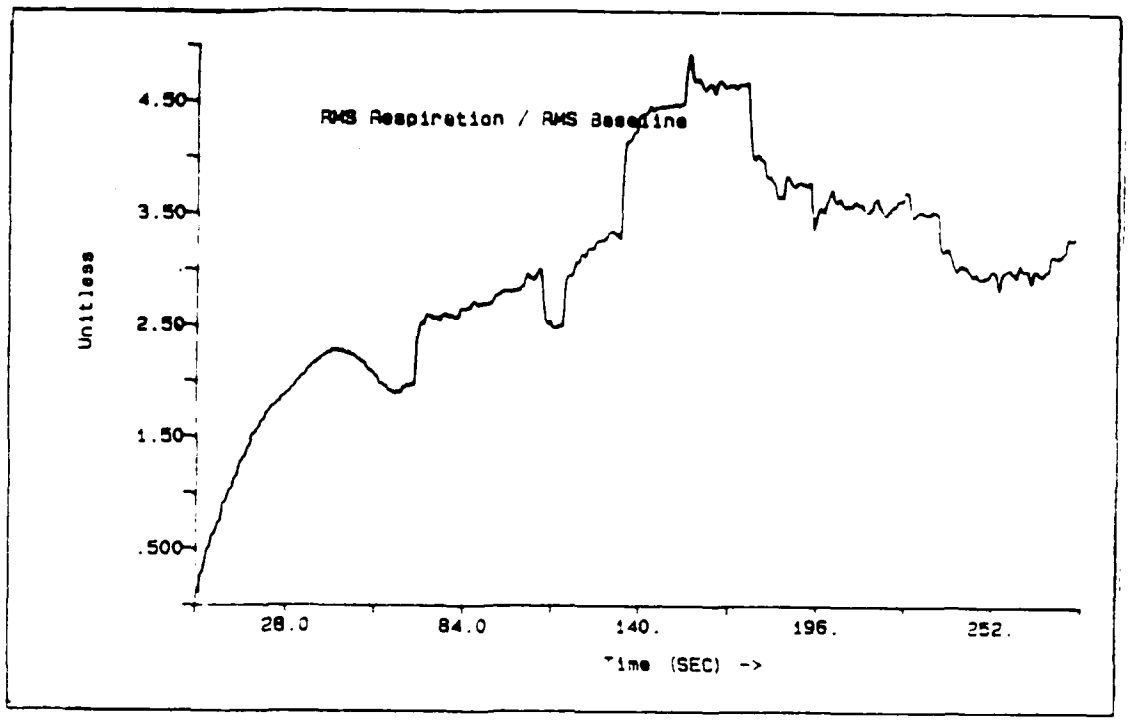


Figure 9. RMS Respiration/RMS Baseline vs. Time

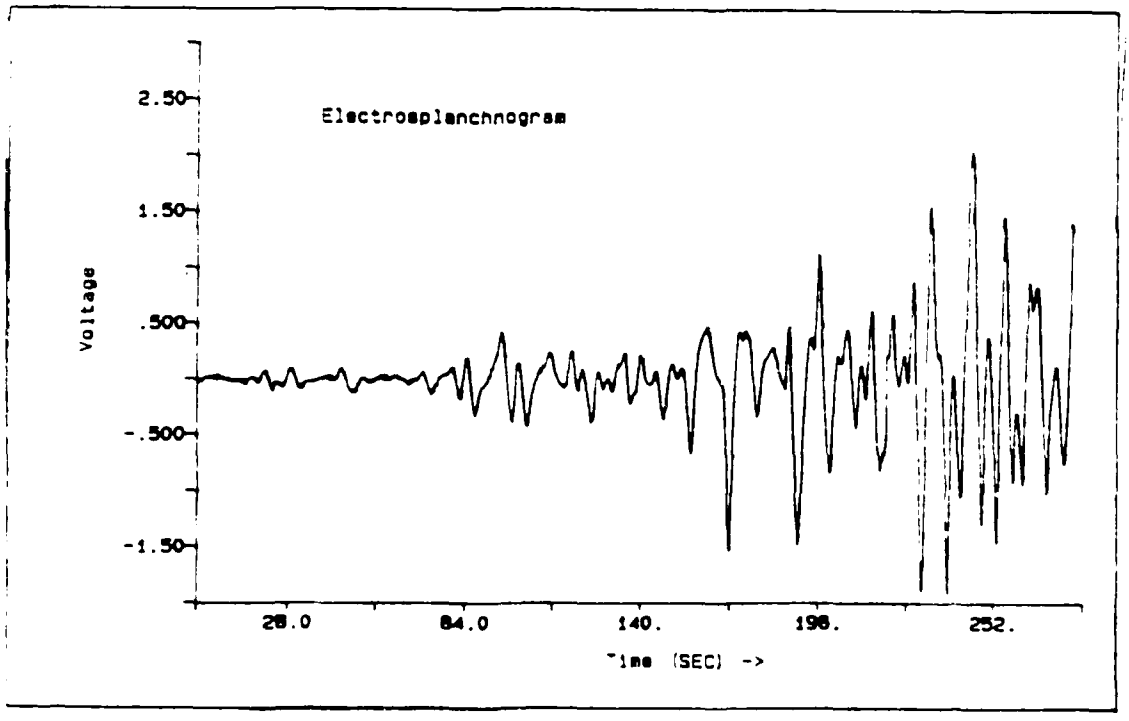


Figure 10. Electrosplanchnogram vs. Time

sickness indicator construction. Figure 11 shows the calculated RMS levels for the ESG data of Figure 10.

The data indicate that a subject's abdominal muscle contractions are relatively low level at baseline and begin to slowly increase in amplitude until the subject is approaching Malaise III, symptom level 7. At this point the increase in amplitude is very dramatic until emesis occurs.

Almost all subjects followed this trend. Only one subject did not, and had no abdominal activity until about 3 seconds before emesis. This was confirmed by her reports of feeling no stomach/abdominal sensations until just before emesis.

Electronystagnogram (ENG). Both horizontal and vertical components of the ENG were measured. The signals observed were due to eye movements but were also interlaced with EEG signals. At the beginning of each experiment the subject was instructed to move his eyes full up, down, right, and left as the researchers recorded the eye movements on the strip chart and Beta recorders. This calibration allowed the determination of the full scale deflections which could be reasonably expected consequent to eye movements alone.

As the experiments progressed all subjects experienced rapid eye movements, at first in response to the start of rotation and then following head movements. The voltage levels observed due to rotation and head movements were low

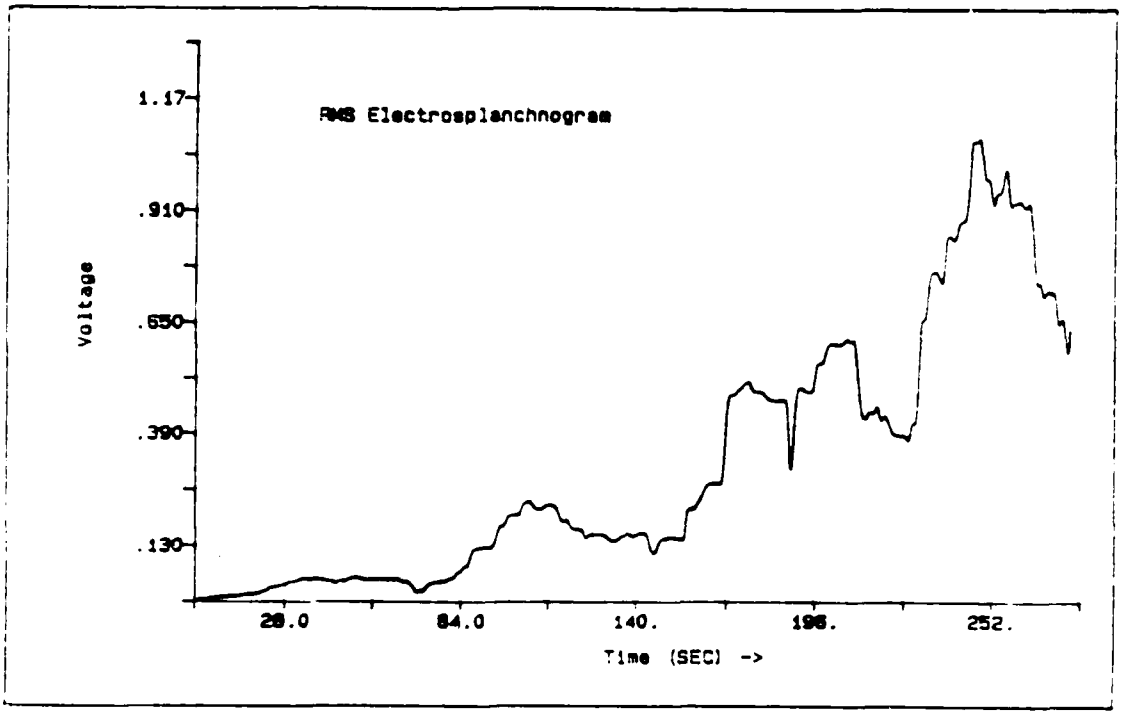


Figure 11. RMS Electrosplanchnogram vs. Time

level in comparison to the baseline calibration (approximately 1/10 or less). As their symptoms worsened, several subjects displayed the high amplitude, low frequency signals as shown in Figure 12. These signals were of much higher amplitude than that generated by the baseline eye movements (approximately 50% larger), and were also seen, at the same time on the EEG channels, but not elsewhere, and thus must be assumed to be high amplitude, low frequency EEG signals. It is believed that these signals might be due to hyperventalation.

As with the previous signals vertical ENG signal levels do not provide a good indication of motion sickness. RMS values of vertical ENG were calculated using

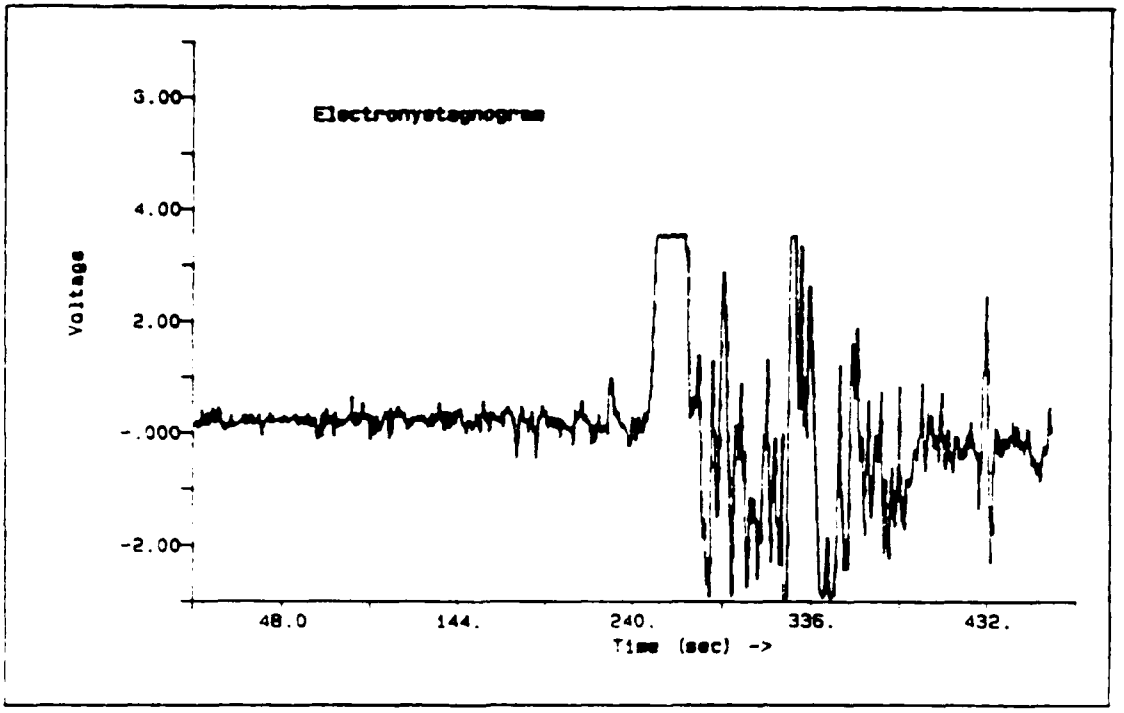


Figure 12. Vertical ENG vs. Time

the procedure described earlier, and were found to be a good indicator of motion sickness. An example is shown in Figure 13.

Electroencephalogram (EEG). Three channels of EEG were recorded again this year. All three channels were recorded on the strip chart recorder, EEG channels B and C were recorded on the Beta recorder, and half way through the experimentation phase we began to record channel A on the Ampex recorder.

The loss of one or more, and often all three, channels of EEG still occurs. The only remedy to date has been to reset the amplifier circuits. While this has always brought back the EEG signals, four or five seconds of data

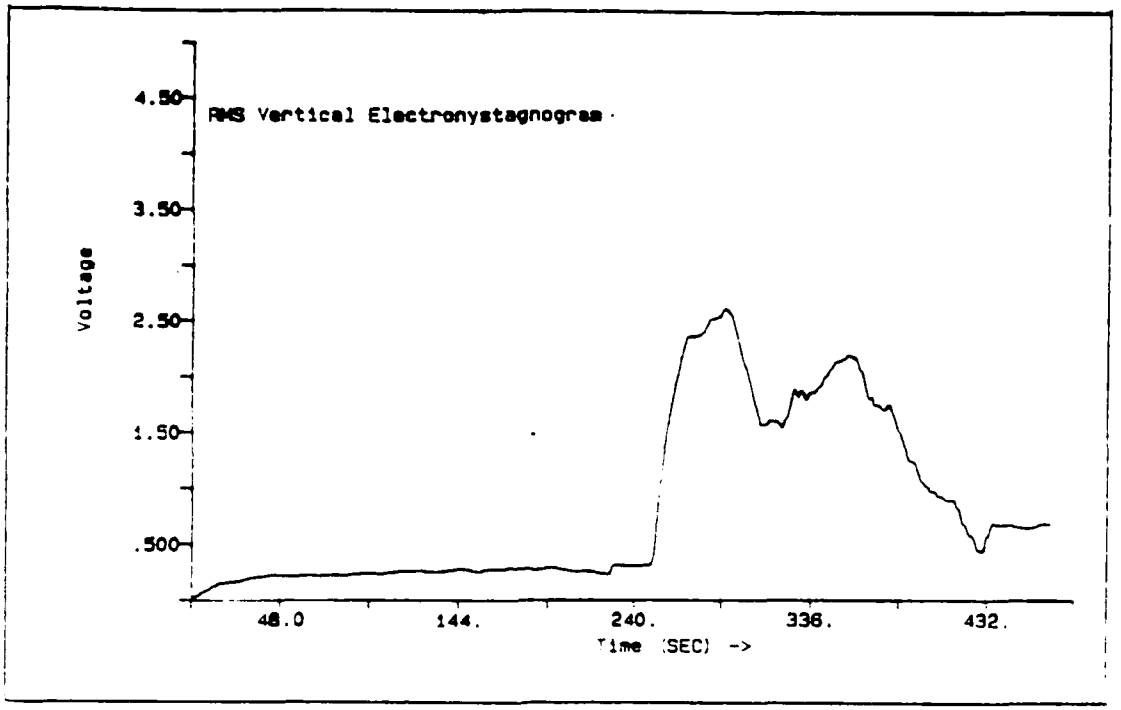


Figure 13. RMS Vertical ENG vs. Time

are lost on all channels. The loss of data is most significant for the data that are input into the real-time processor. Due to the unreliability of the EEG signals they have not been used in the motion sickness indicator at this time.

As subjects progress towards motion sickness their EEG signals displayed the dramatic increase in amplitude, decrease in frequency described in the ENG section. This signal was induced in one subject by having him hyperventilate while not under going any motion stimuli (1). This indicates that the low frequency signals may be due to hyperventilation. It is unclear why some other subjects do not exhibit the high amplitude, low frequency

signals even while hyperventilating. More information on hyperventilation may be found in the thesis by Captain Gaudreault.

Pallor. As mentioned in Chapter II. the method of determining percent pallor changed this year in three areas: circuitry, sensor design, and sensor placement. As these changes took place over the course of the experimentation phase, little data were collected under a single set of circuitry, sensor design, and sensor placement. For this reason percent pallor was not used in the motion sickness indicator.

Motion Sickness Indicator

Processing of Galvanic Skin Response, Temperature, Respiration, Electrosplanchnogram, and Electronystagnogram signals produced data which are good indicators of motion sickness. This thesis team developed a motion sickness indicator using all five of the above signals, but each of these signals by themselves could possibly be used in an indicator. Five signals were used in the indicator because:

1. Five signals provided increased reliability. In several runs one or more of the data channels would not function.
2. Five signals allow better modeling of subjects which exhibit only a few of the motion sickness symptoms.
3. Five signals provided a more accurate indicator than indicators using less than five signals.

4. The analog-to-digital converter was capable of handling up to eight channels of data. It was decided to develop an indicator which would use the full capabilities of the computer but not introduce time delays which would render the system useless for real-time processing.

While this thesis team used five signals in its indicator, further improvements may be made by including additional signals. Skin Pallor appears to be a good indicator of motion sickness. The pallor circuitry and sensor has been modified and should provide good data for curve fitting to allow pallor to be used in the motion sickness indicator. More information on the motion sickness indicator may be found in the thesis by Captain Edward Fix.

V. Conclusions and Recommendations

Conclusions

The conlusions will cover four main areas: system performance, data analysis, susceptibility tests, and the motion sickness indicator.

System Performance. There are two areas of system performance: chair performance and circuitry performance.

The chair performed well throughout the summer with only a few complications. The most significant problem encountered forced experimentation to stop for approximately three weeks due to the wear out of the chair bearings. This was apparantly caused by lack of sufficient lubricant. The bearings were replaced and it was discovered that lubricant can be added from the underside of the chair. This should be done regularly.

Circuitry/Sensor Performance. Several minor circuit/sensor problems were encountered during experimentation. These problems were bent pins, loose or bad circuit chips, loss of common ground, and strain gauge breakage. These problems were minor inconveniences and caused only slight delays in the experiments. In only one case, loss of common ground, all data were lost for an experiment.

Susceptibility Tests. The susceptibility tests show promise in determining what rotational velocity is optimum for the full runs. Ideally, the full run should last

between five and ten minutes. In experiments of less than five minutes, a subject's physiological signals tend to change slower than his level of sickness and in experiments of greater duration than 10 minutes, the data base becomes too large to be adequately handled by "Asystant" without breaking the data into chunks.

The susceptibility testing was started late in the experimentation phase and hence little data were collected to come up with exact calculations of the stress levels for head movements using the AFIT protocol.

Motion Sickness Indicator. The motion sickness indicator, described in the thesis by Captain Fix, has worked well using Beta tapes played back as real-time data. Usually, the indicator is within 1 level of what the subject is reporting. It can be used now as an indicator and in the future development of a predictor. The usefullness of the indicator in an aircraft or space vehicle is undetermined at this time because while the five signals measured are easily connected and calibrated, if the crew member is in a large aircraft or space vehicle and can move around, detachable electodes must be used if the crew member is to be able to leave his seat.

Recommendations

Following are the recommendations for continuation of this thesis project. The main areas of recommendations are in susceptibility tests, improvement upon the motion sickness indicator, equipment, circuitry, and experimental

changes. These recommendations are presented in the order that is believed to be most beneficial to a subsequent thesis team.

Susceptibilty tests. Susceptibility tests should be run on every subject prior to the full experiment. Follow on thesis teams should attempt to run at least 50 susceptibility tests in the early stages of their thesis work. Several subjects should undergo both the AFIT and Graybiel protocols. Running the volunteers early in the program and under both protocols will accomplish several important tasks. The subjects will be screened as to susceptibility, the chair velocities to be used in the full run will be determined, the researchers will become familiar with the equipment, the AFIT-Graybiel head movement stress level comparison can be completed, and a baseline may be started to find out what CSSI level could serve as a threshold in predicting whether a subject could complete flight training or not.

Personnel whom have been disqualified from flight traing due to motion sickness should be brought TDY to AFIT for CSSI tests. In addition, CSSI tests should be accomplished on as many persons on flying status as possible. This may allow the derivation of CSSI threshold levels to be determined separating those whom are too susceptible to be allowed into flight training from those are unsusceptible to motion sickness and those whom are susceptible to motion sickness, but can be trained to control the symptoms.

Future susceptibility tests should include the monitoring of GSR and possibly other channels of data which do not require extensive calibration time. Care should be taken to ensure that the susceptibility test maintains its strongest point, shortness of the time required to complete an experiment. That is, subjects willing to take the susceptibility test because of its short duration (less than 10 minutes) may not be willing to volunteer if the test time is extended. Adding more than a few signals, or signals that require calibration will extend the test time and possibly reduce the number of volunteers.

Equipment Changes. Several equipment changes are necessary. A signal multiplexing system must be placed into the data collection loop to allow additional data channels and the pitch and roll commands to be implemented. Along with the pitch and roll commands a computer program should be implemented into the control loop to control the pitch, roll, and chair velocity commands at a constant rate, independent of the operator.

Additional equipment would greatly enhance the data collection and processing capabilities for the motion sickness laboratory. A Beta recorder has been ordered to allow the recording of all data on Beta tapes. A third Beta recorder should also be ordered if the data processing will not be completed in the same area as the lab. Other items required are a video camera (used to monitor, and obtain a visual hard copy of, eye movements, sweating, and pallor), a

device for monitoring the pH levels of a subjects blood, and a device for monitoring the carbon dioxide output in a subject's breath.

The motion sickness indicator developed by this thesis team should be implemented into a biofeedback loop using the monitor in the chair.

Circuitry Changes. The EEG and GSR circuits require some modification. The EEG amplifiers sometimes saturate as a subject approaches emesis. The current "cure" for this problem has been to reset the amplifiers, which causes the temporary loss of all data channels for about five seconds. The circuits were modified which reduced the rate of saturation occurance.

The skin resistance measured by the GSR sensors and circuitry has dropped below zero for several subjects this year, but only during the experiment. As this data was obviously in error, the GSR circuitry was modified. Experiments need to be completed with the modified circuitry to determine if the problem has disappeared.

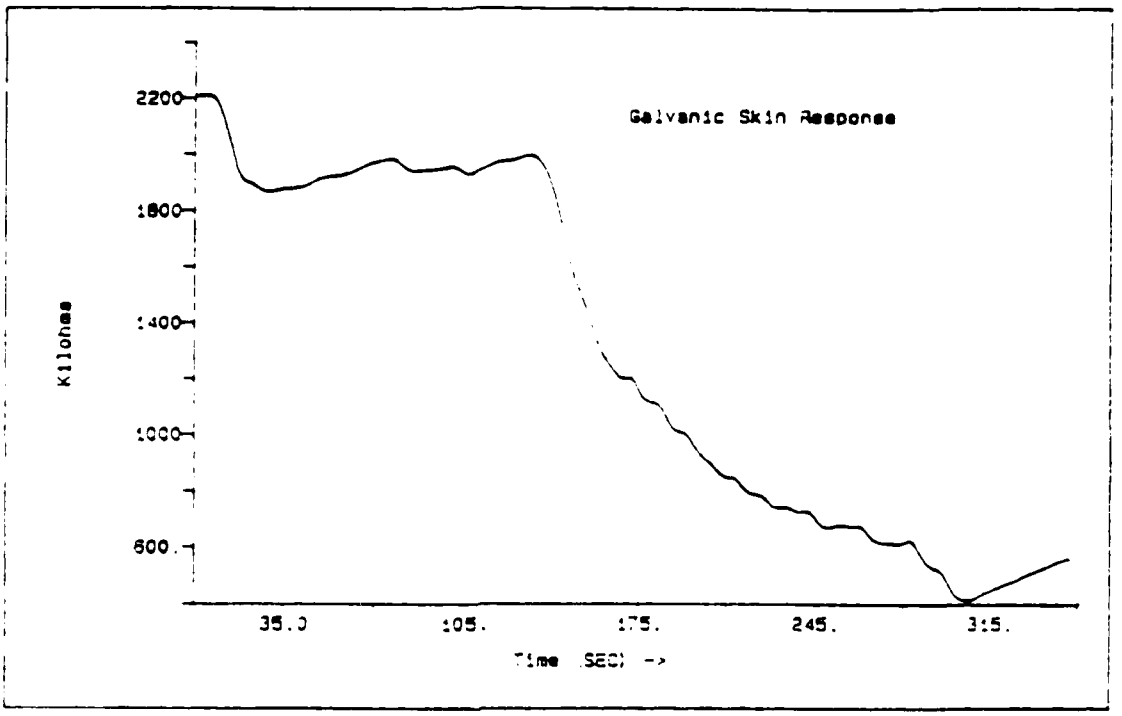
Motion Sickness Indicator. The motion sickness indicator and real-time processor require additional testing to allow further refinement of the equation and processor. The data collected this year should be evaluated to determine if higher order polynomials, or possibly a sinusoidal, logarithmic, exponential, or some combiation of the above better represents the physiological data/motion sickness relationship.

Appendix A: Data

This Appendix contains the physiological data which was used to derive the motion sickness indicator. Subject data which was considered "bad" was not used, and is not shown. Not all subjects used in the experiment have their data listed in this appendix because of unsusceptibility to motion sickness, medication being used by the subject prior to the experiment, or equipment malfunction.

The data is presented in the following order:

Figure #	Title
14 - 18	Skin Resistance as a Function of Time
19 - 25	Temperature as a Function of Time
26 - 34	Respiration Voltage as a Function of Time
35 - 44	ESG as a Function of Time
45 - 50	Vertical ENG as a Function of Time


Galvanic Skin Response
2200
1800
1400
1000
600
Kilohms
35.0
105.
175.
245.
315.
Time (SEC) ->
Galvanic Skin Response
300.
500.
300.
100.
48.0
144.
240.
336.
432.
Time (SEC) ->
Figure 14. Skin Resistance as a Function of Time
Figure 15. Skin Resistance as a Function of Time

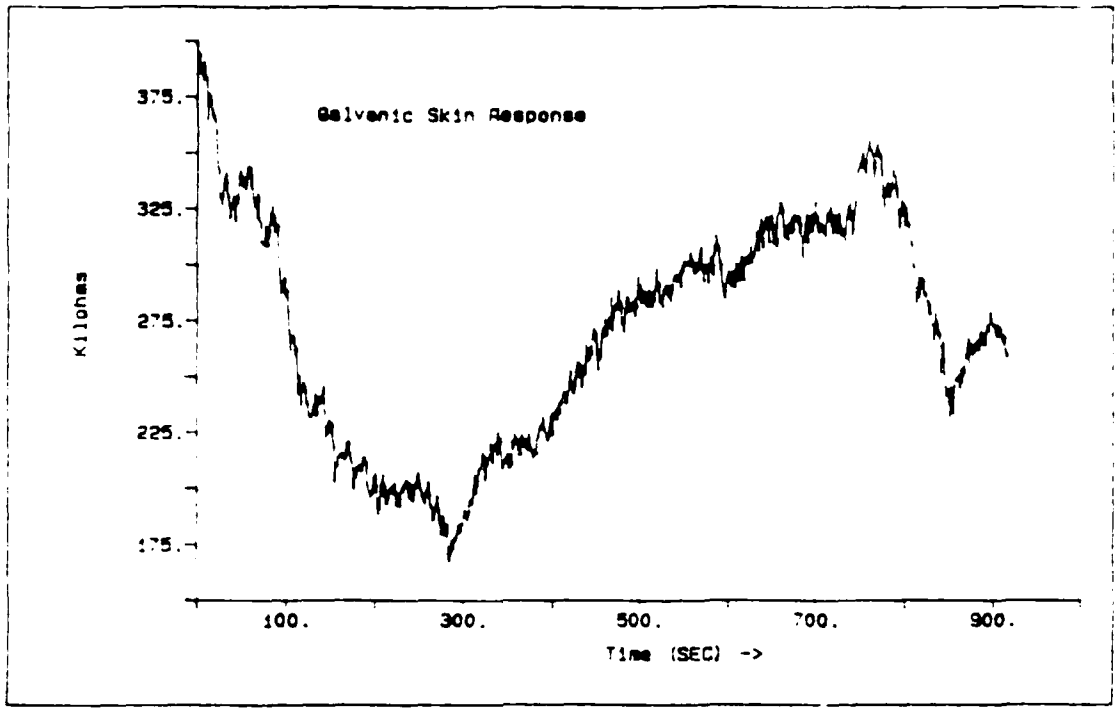


Figure 16. Skin Resistance as a Function of Time

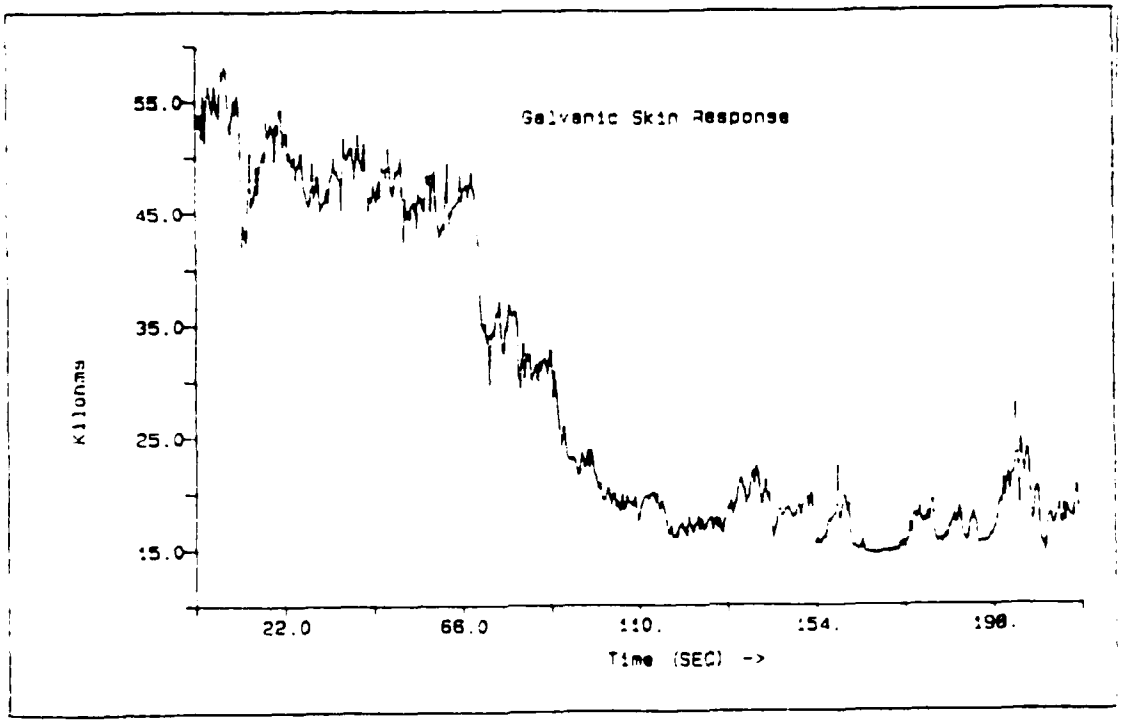


Figure 17. Skin Resistance as a Function of Time

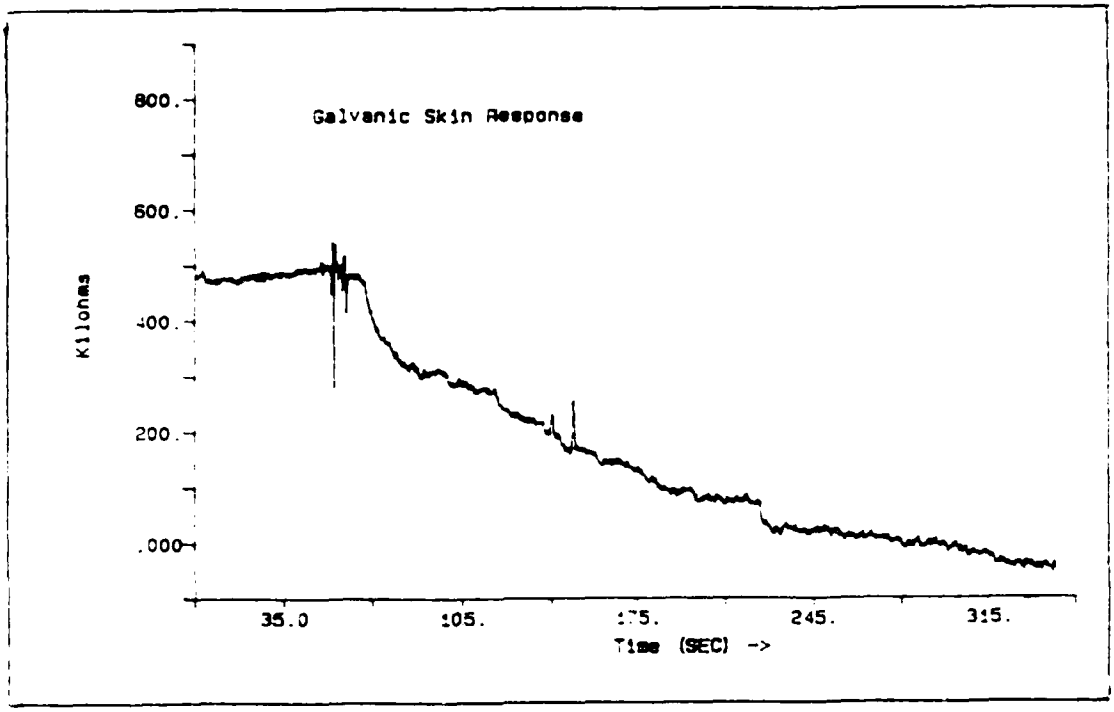


Figure 18. Skin Resistance as a Function of Time

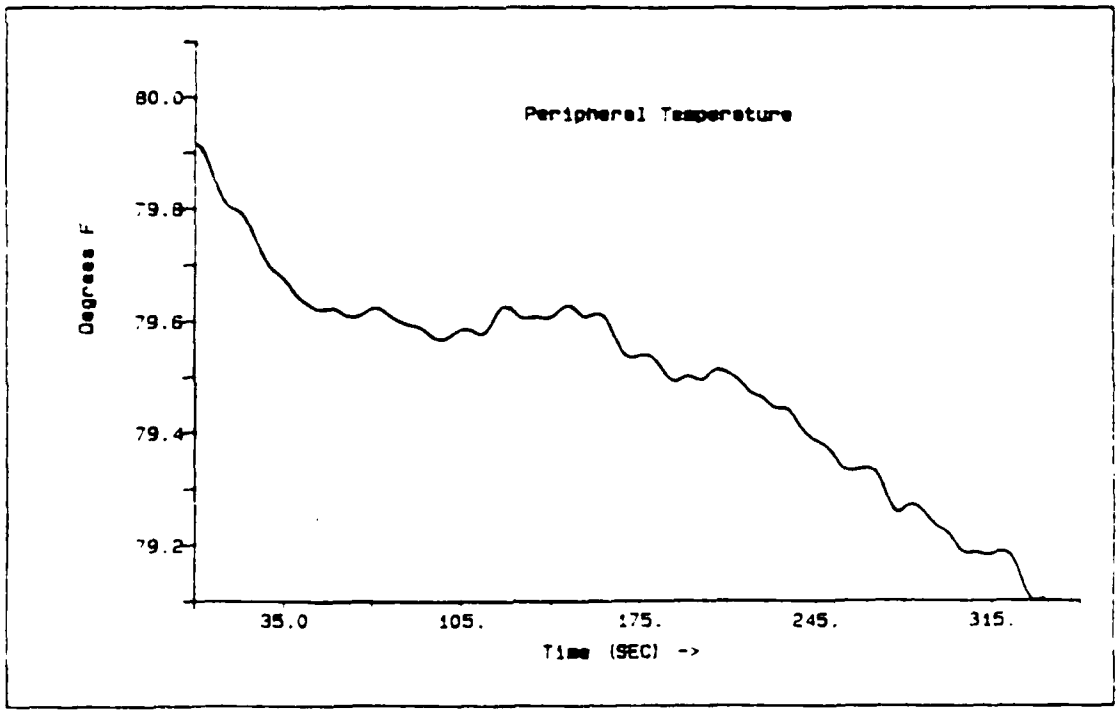
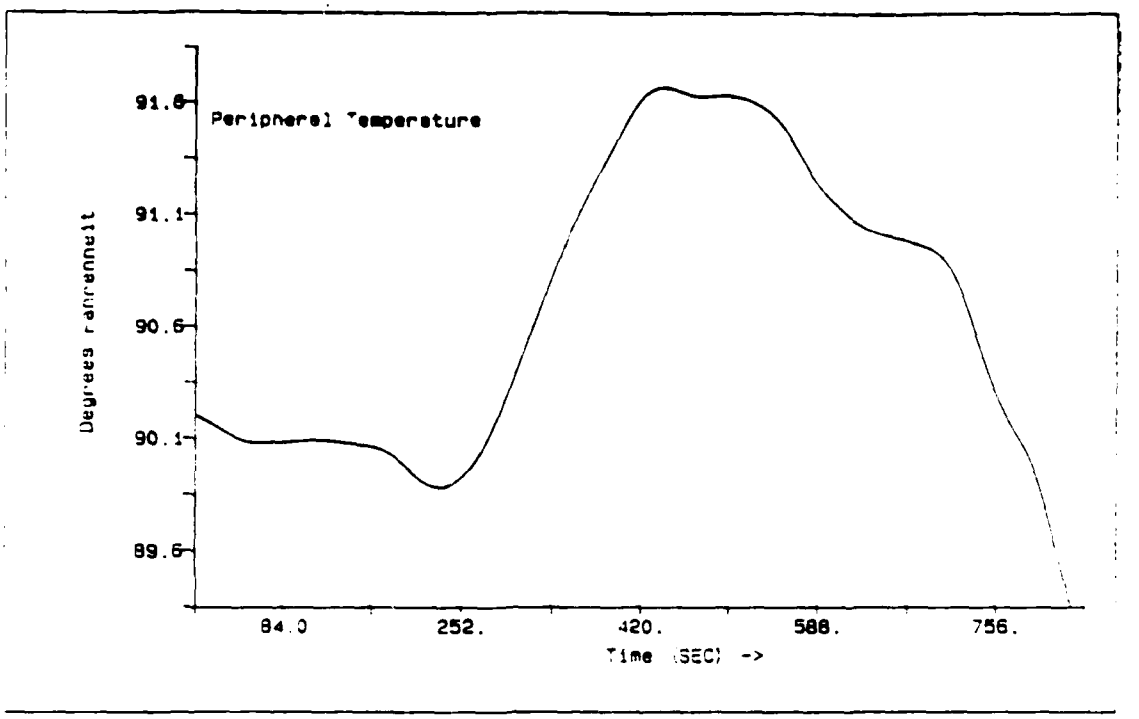


Figure 19. Temperature as a Function of Time



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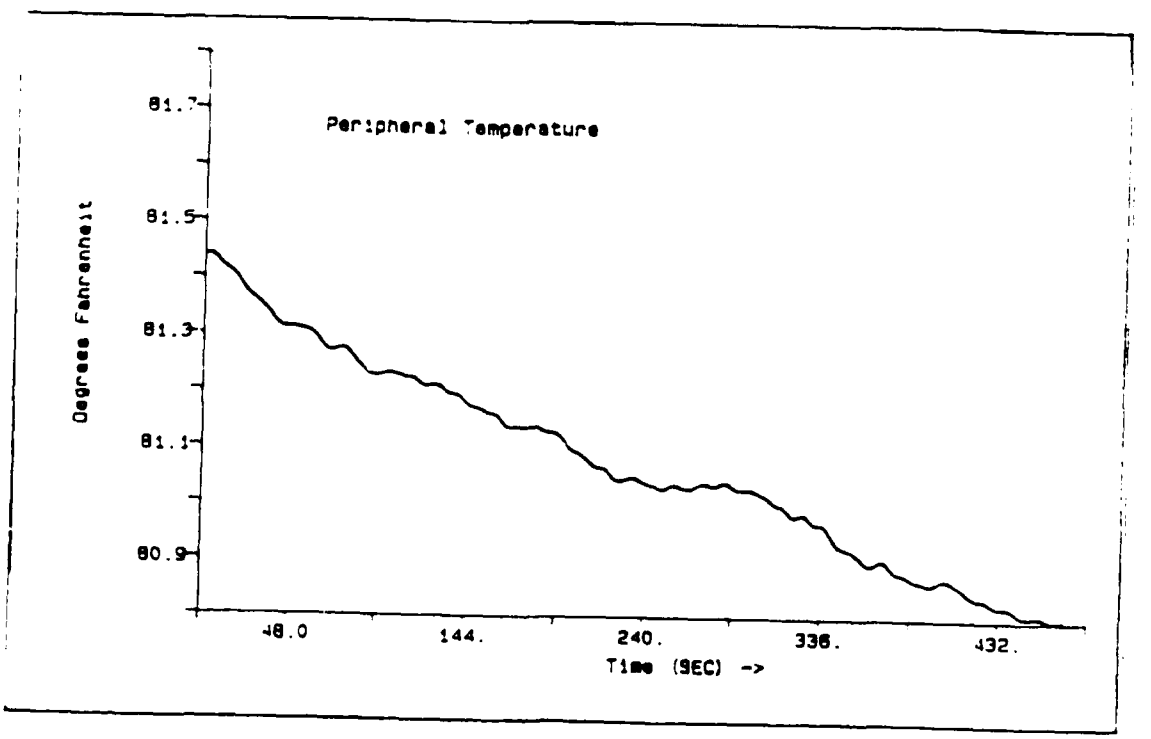
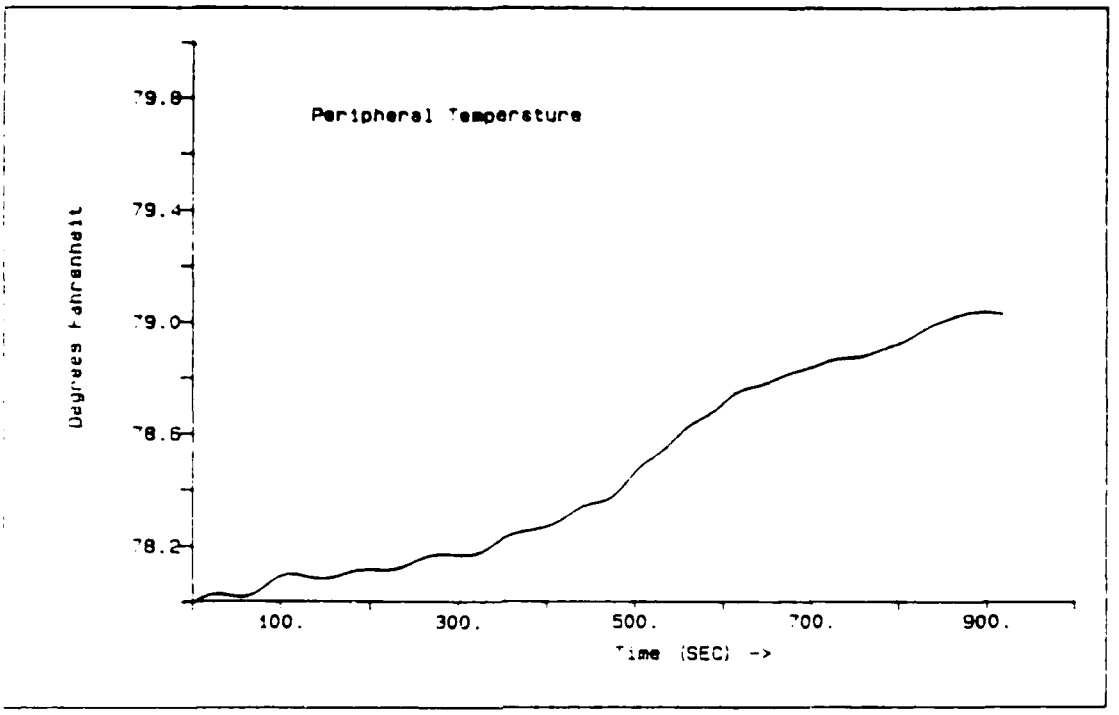


Figure 21. Temperature as a Function of Time



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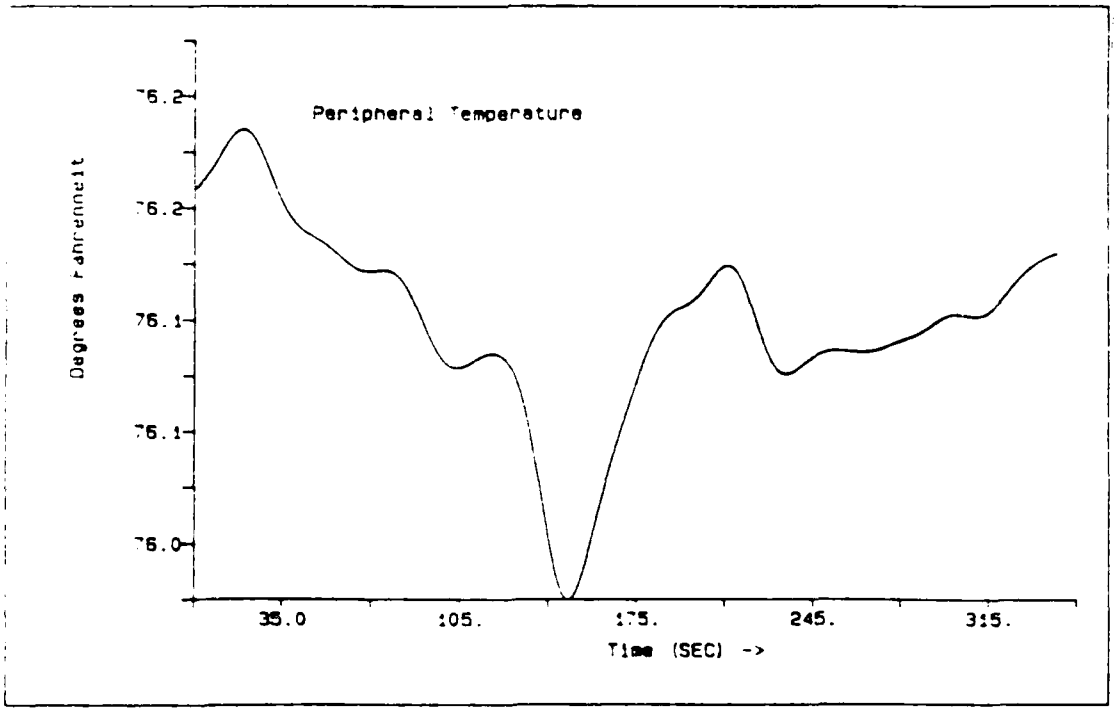

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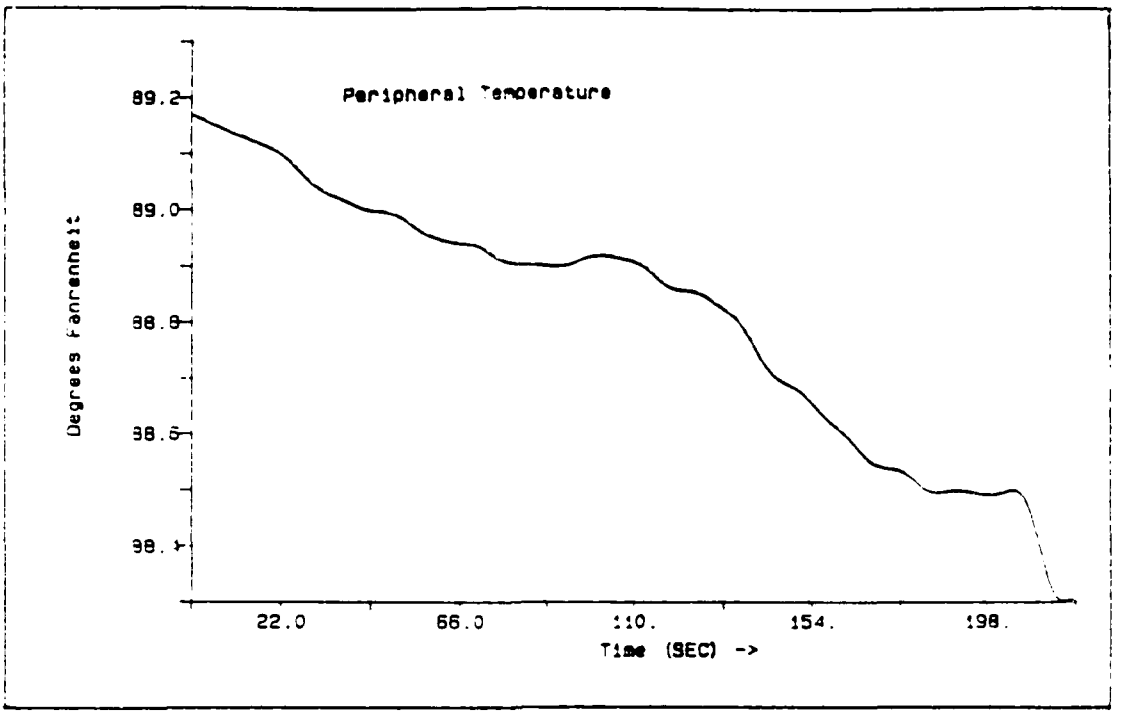

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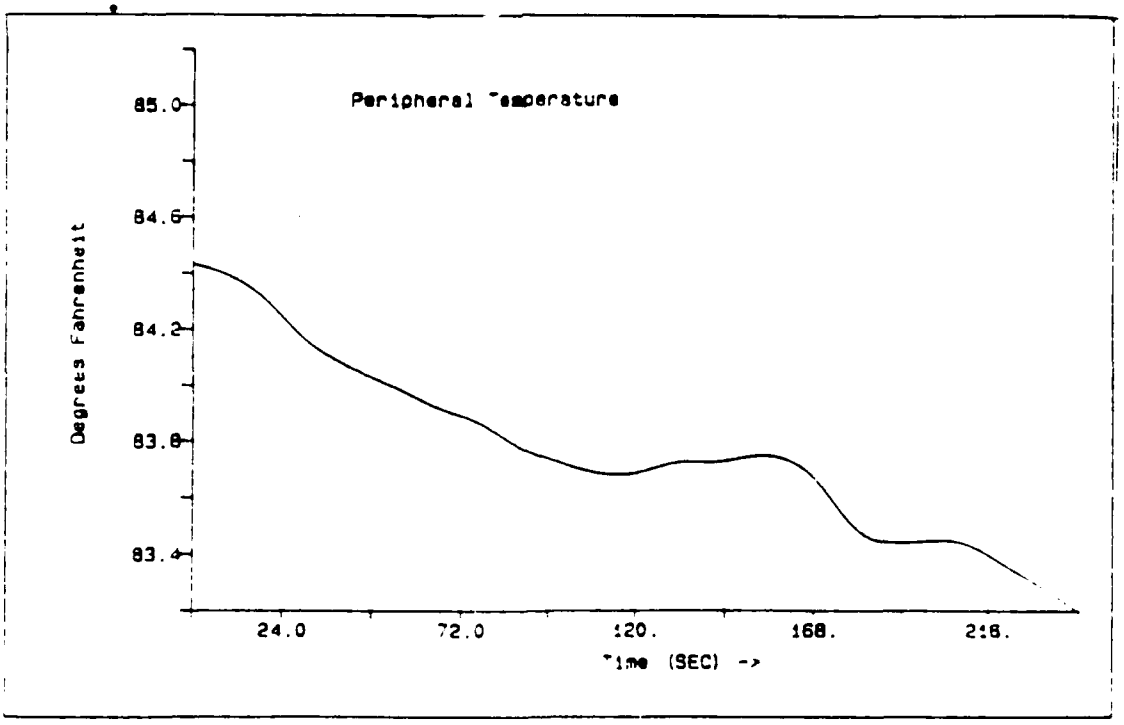


Figure 25. Temperature as a Function of Time

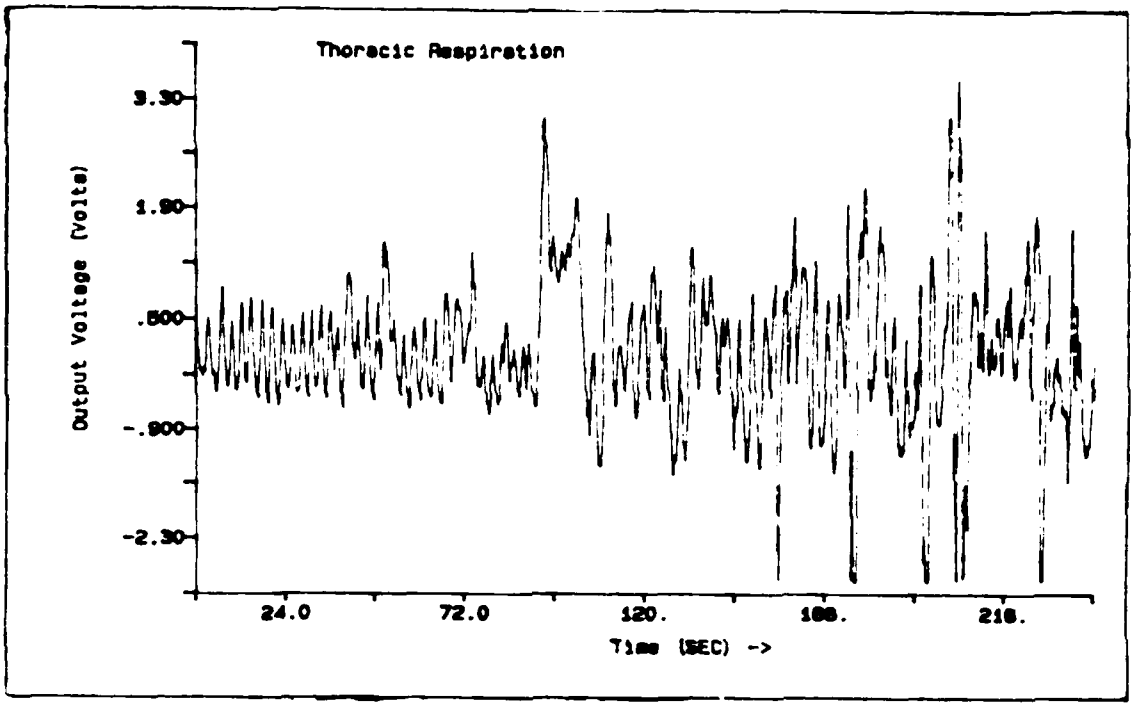


Figure 26. Respiration Voltage as a Function of Time

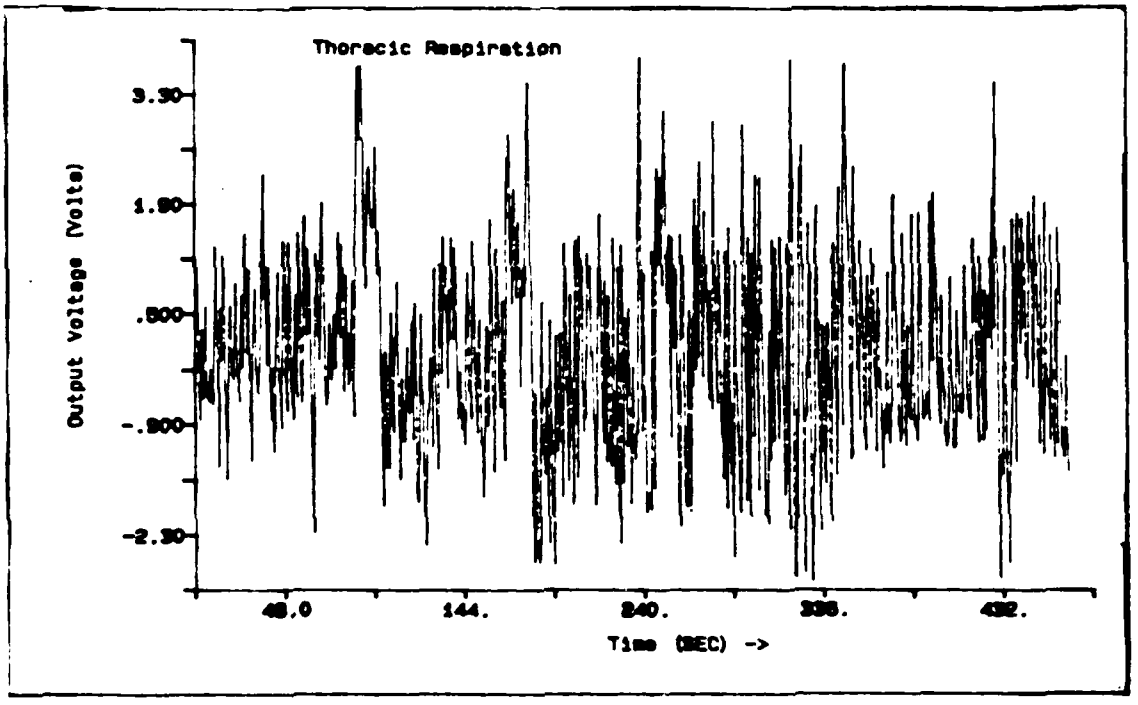


Figure 27. Respiration Voltage as a Function of Time

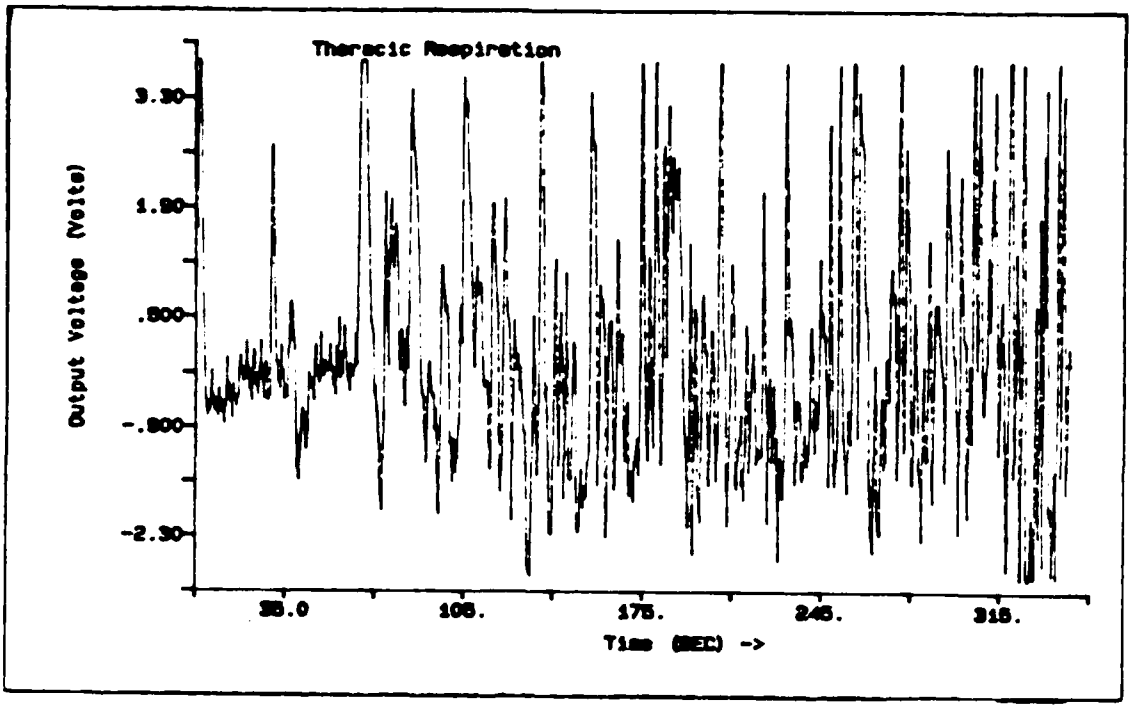


Figure 28. Respiration Voltage as a Function of Time

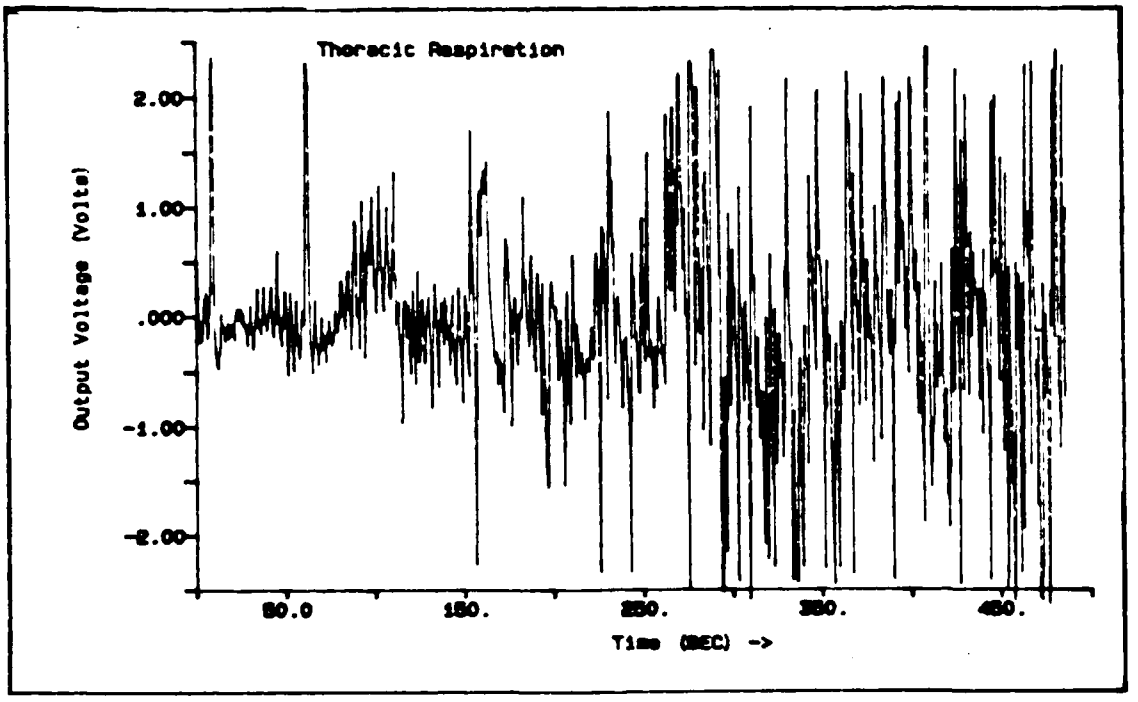


Figure 29. Respiration Voltage as a Function of Time

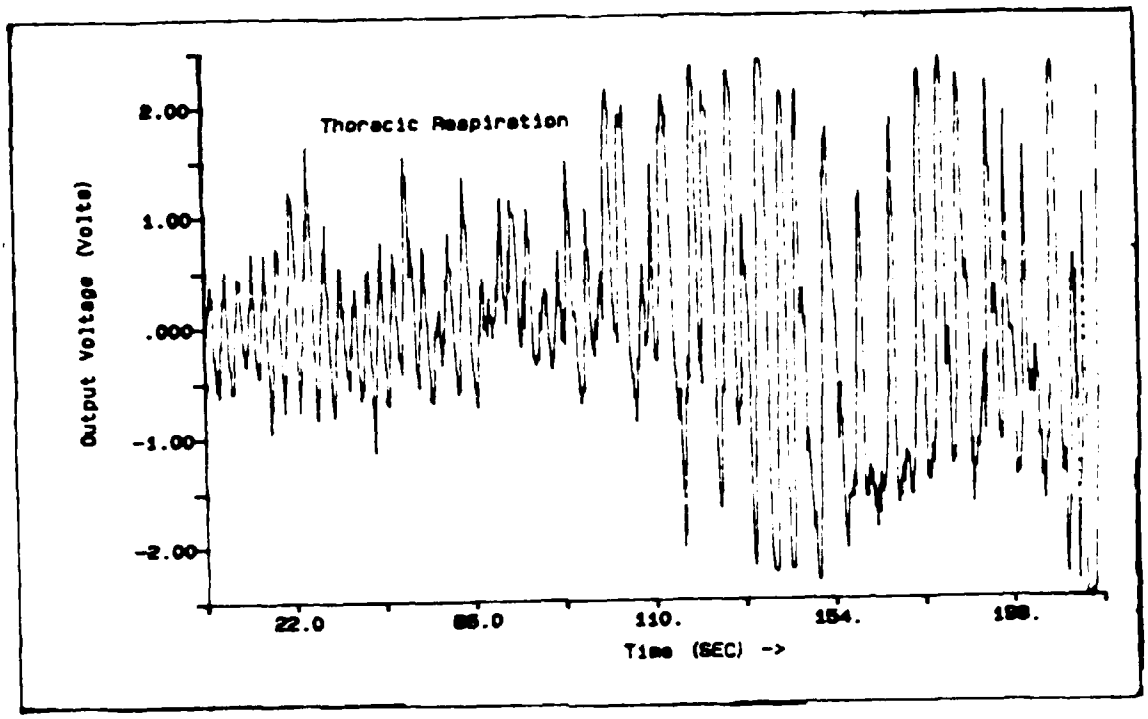
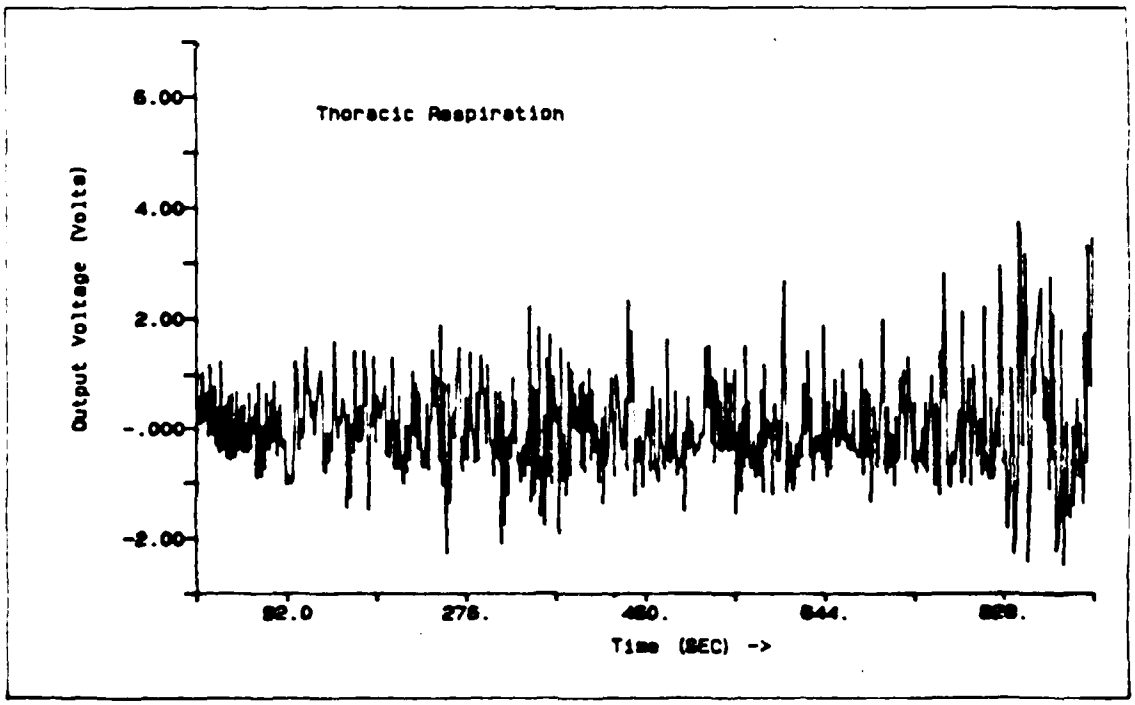


Figure 30. Respiration Voltage as a Function of Time



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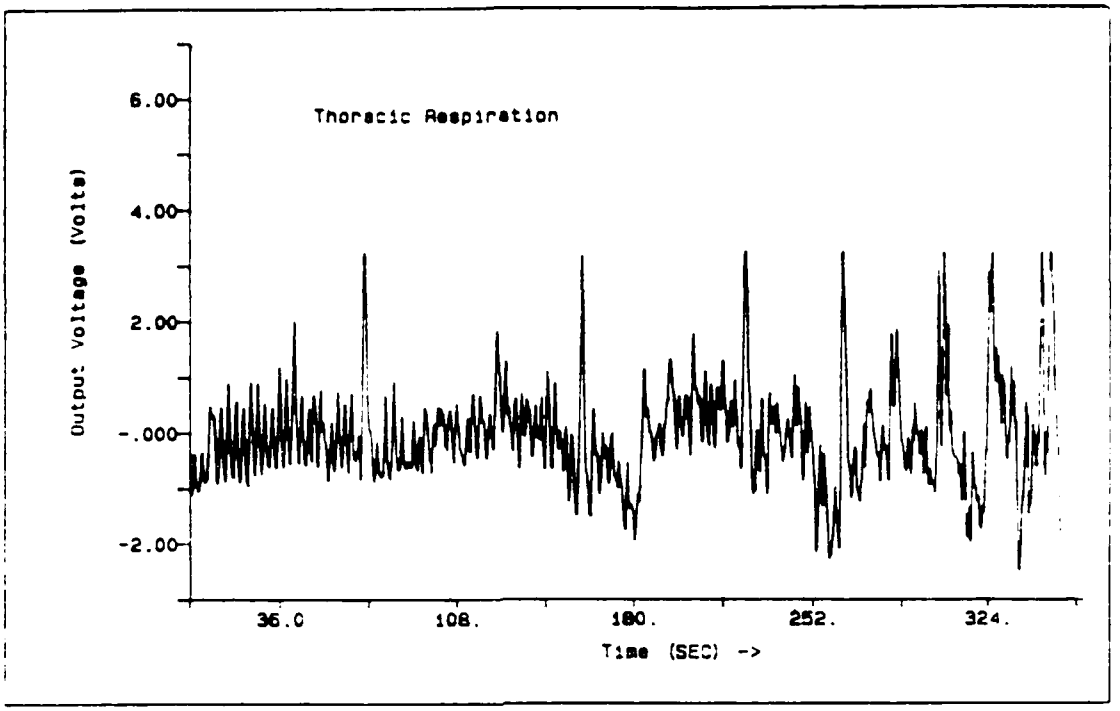

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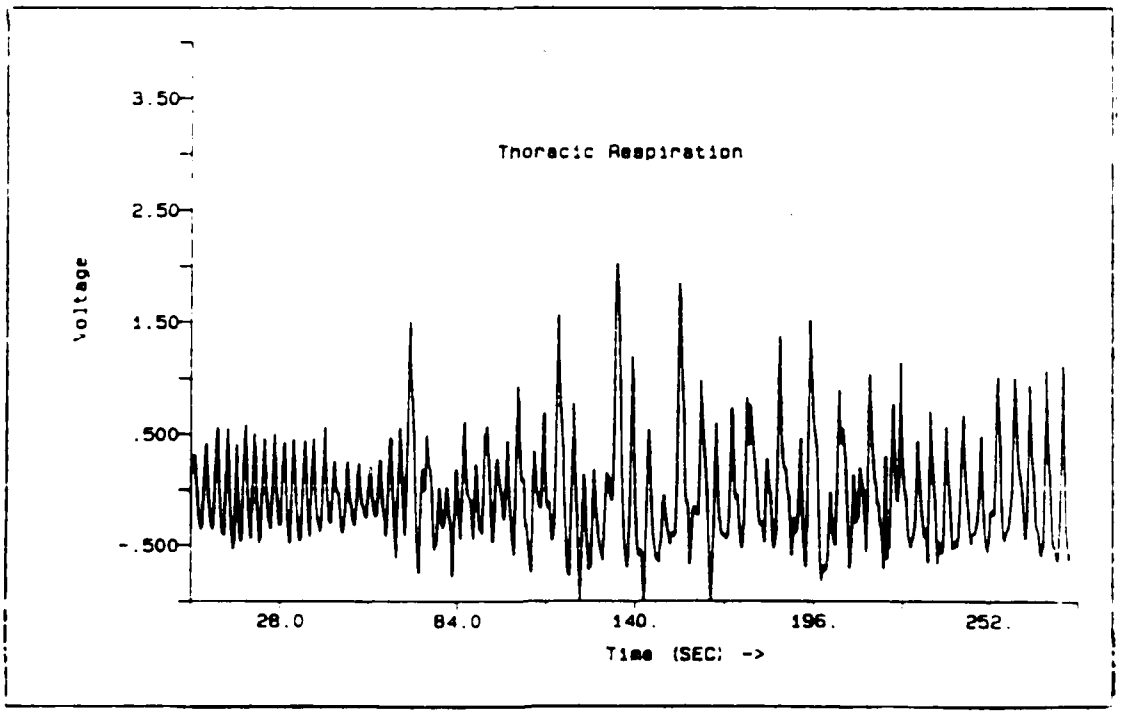
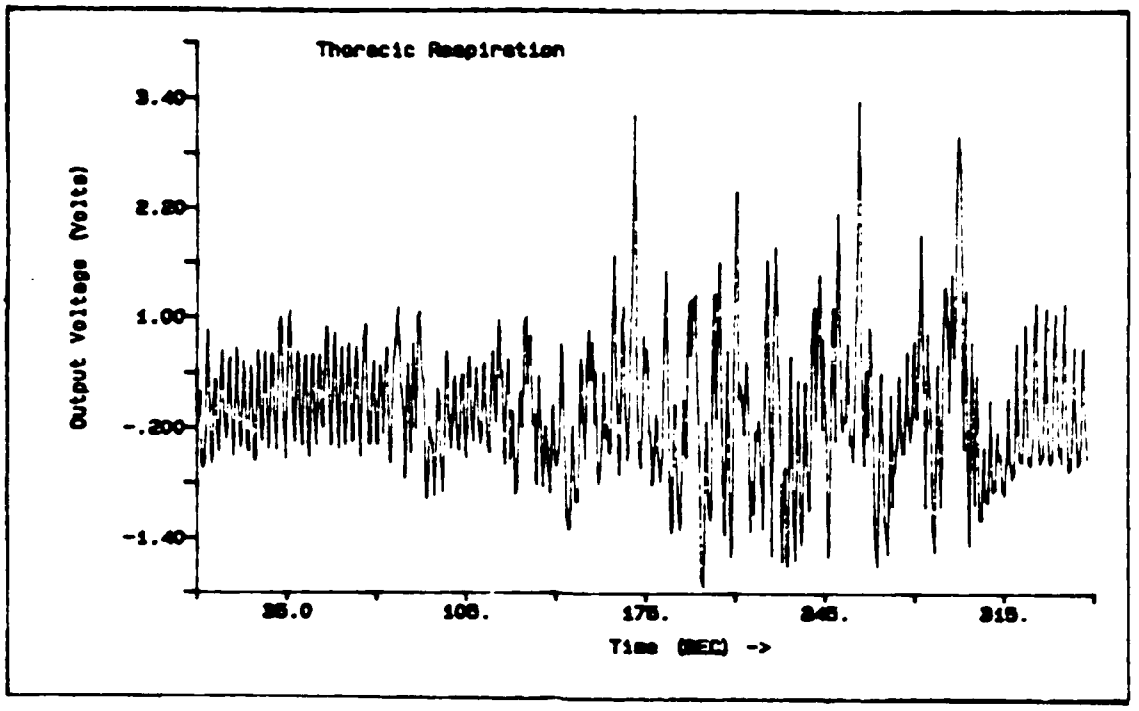


Figure 33. Respiration Voltage as a Function of Time



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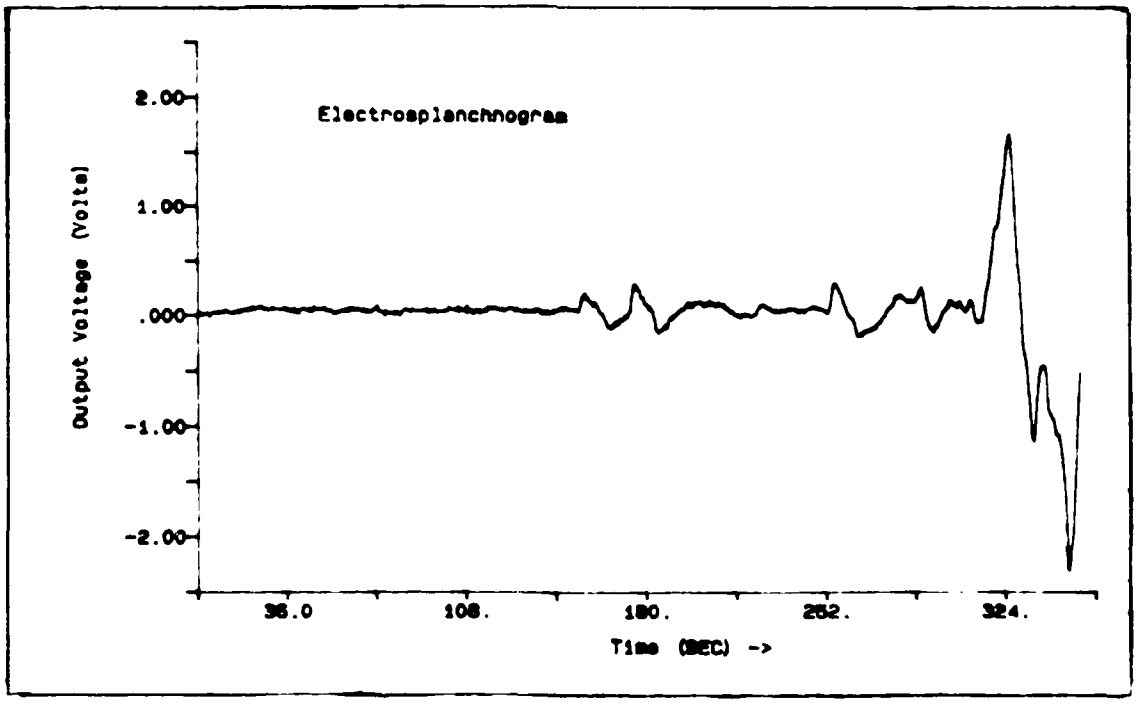

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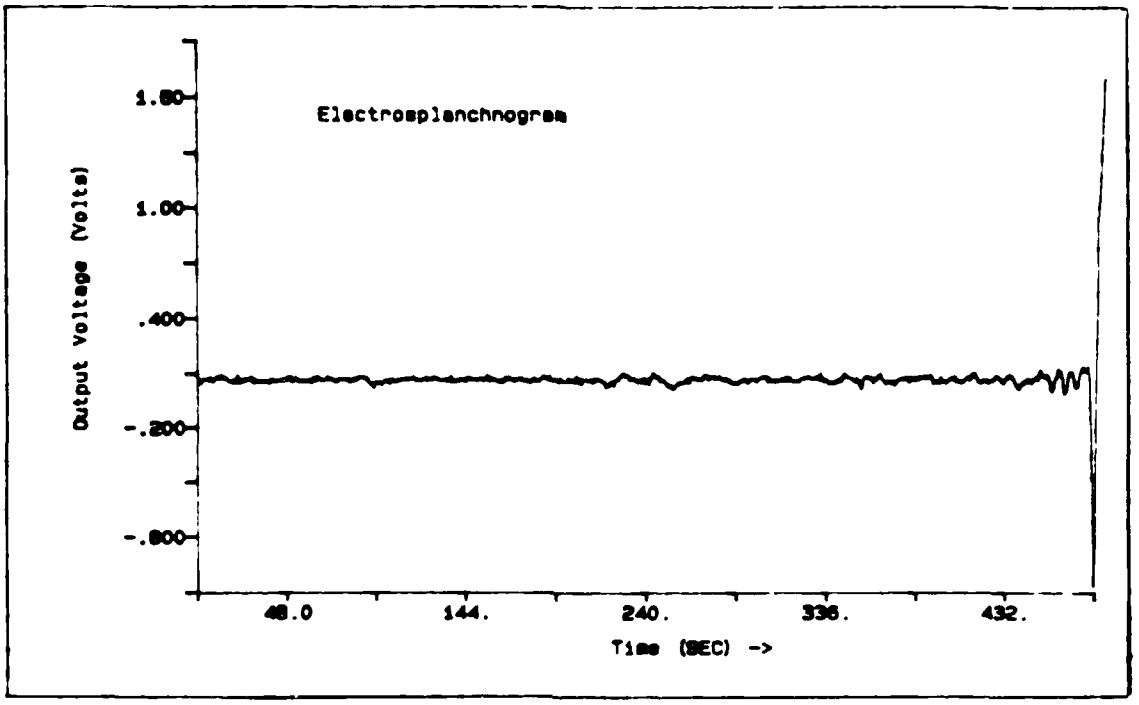

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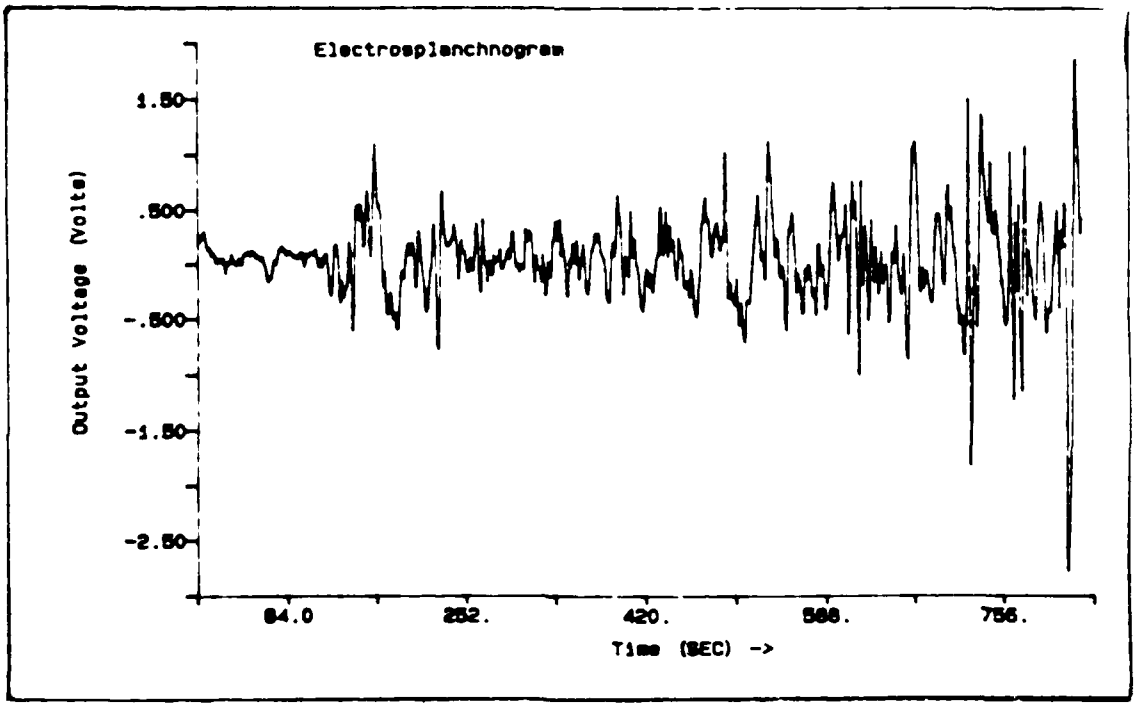

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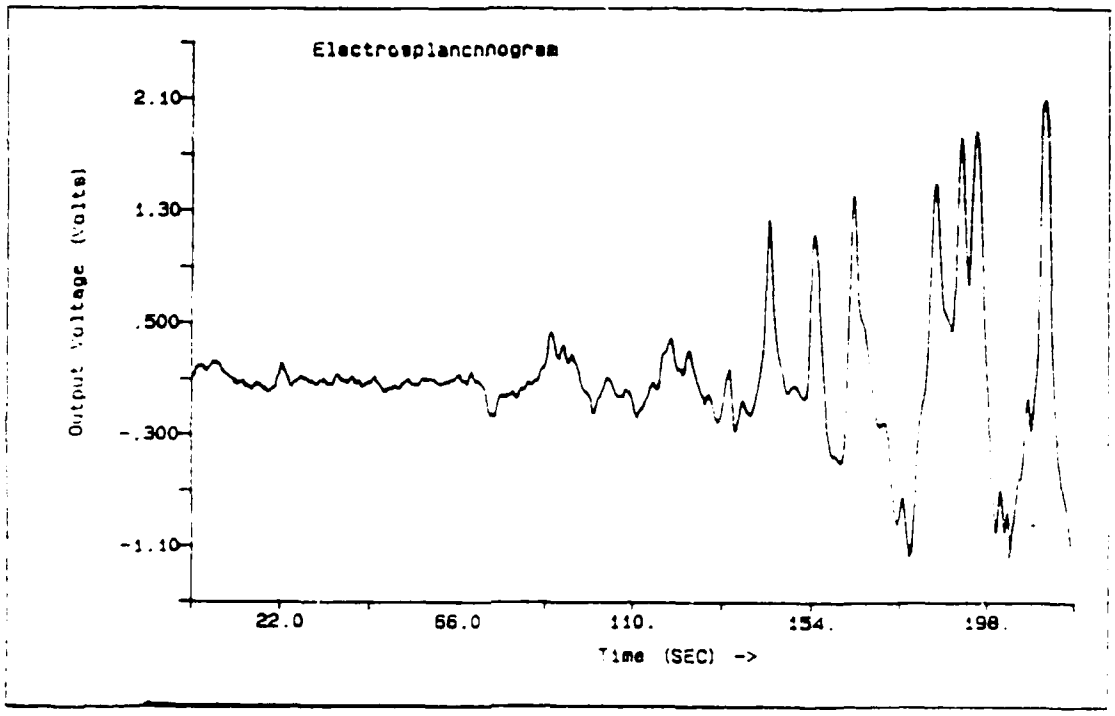

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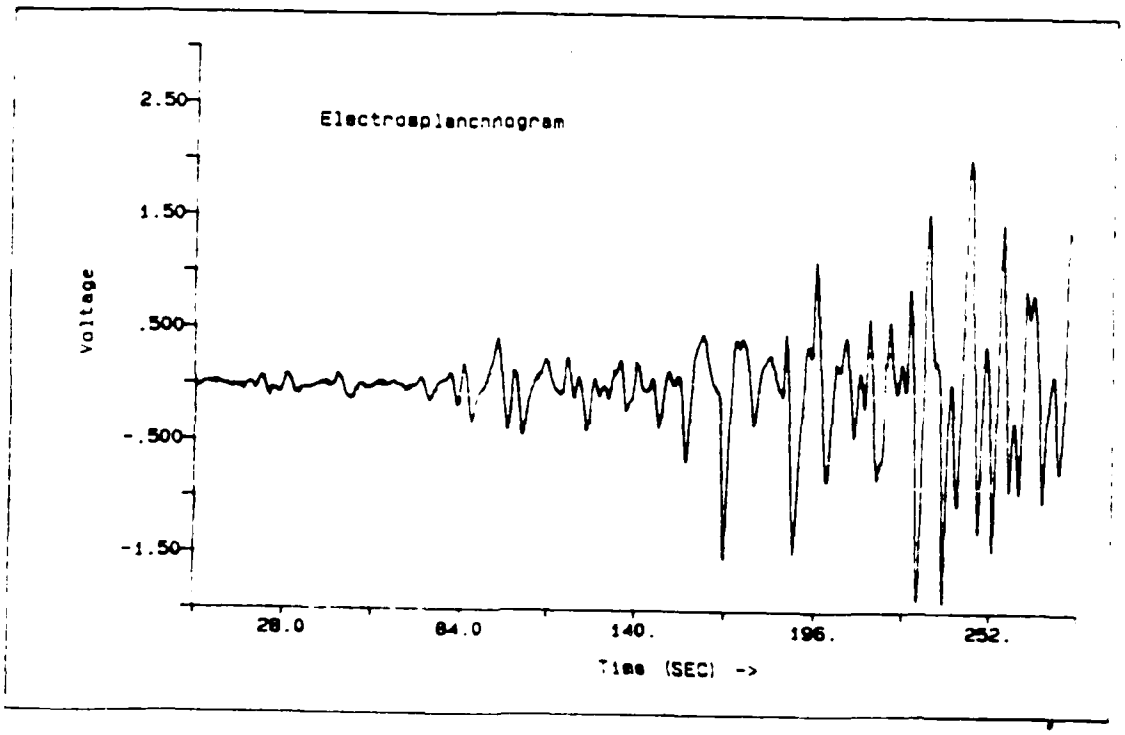

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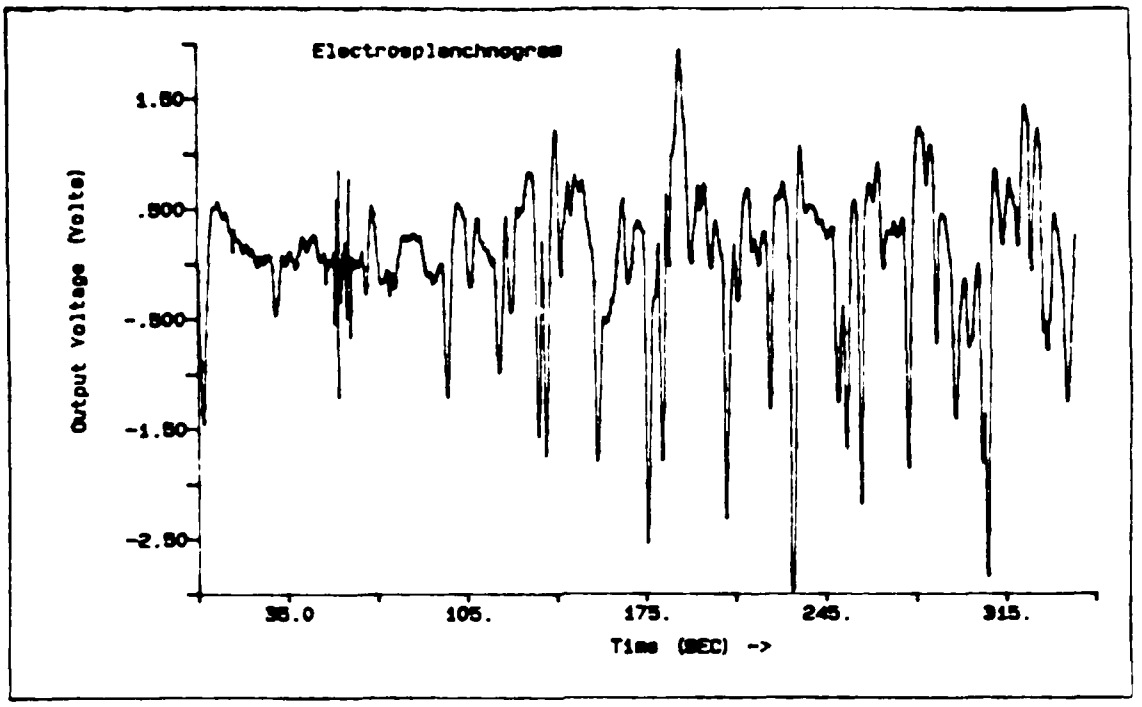

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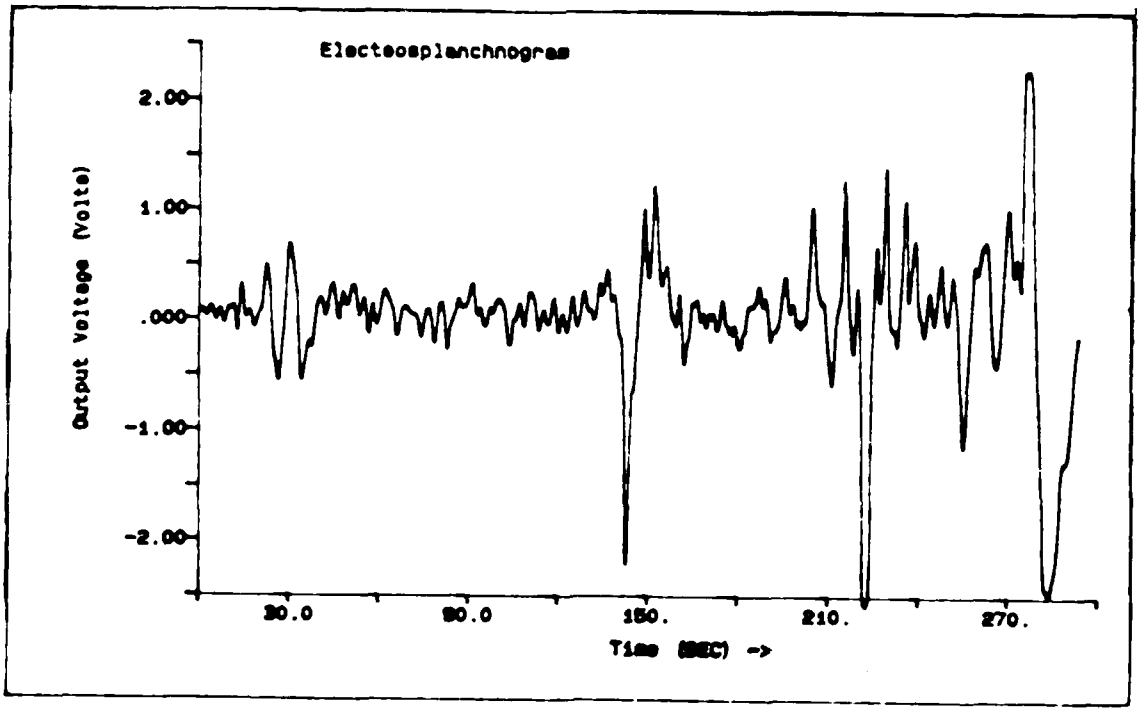

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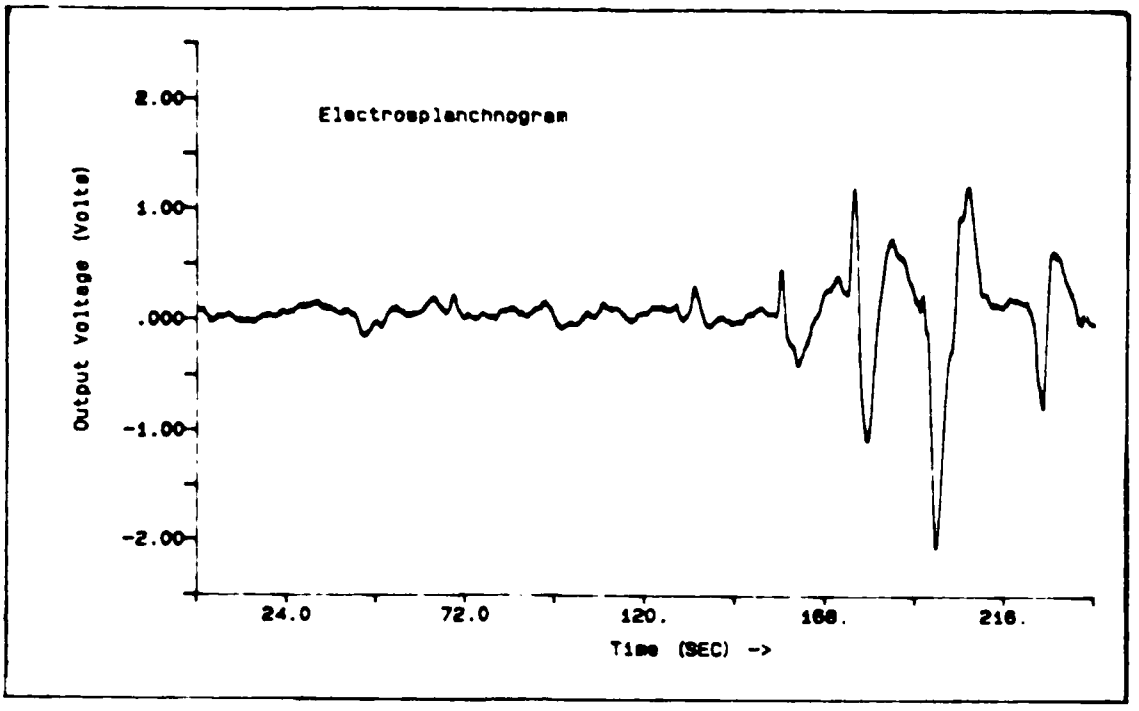

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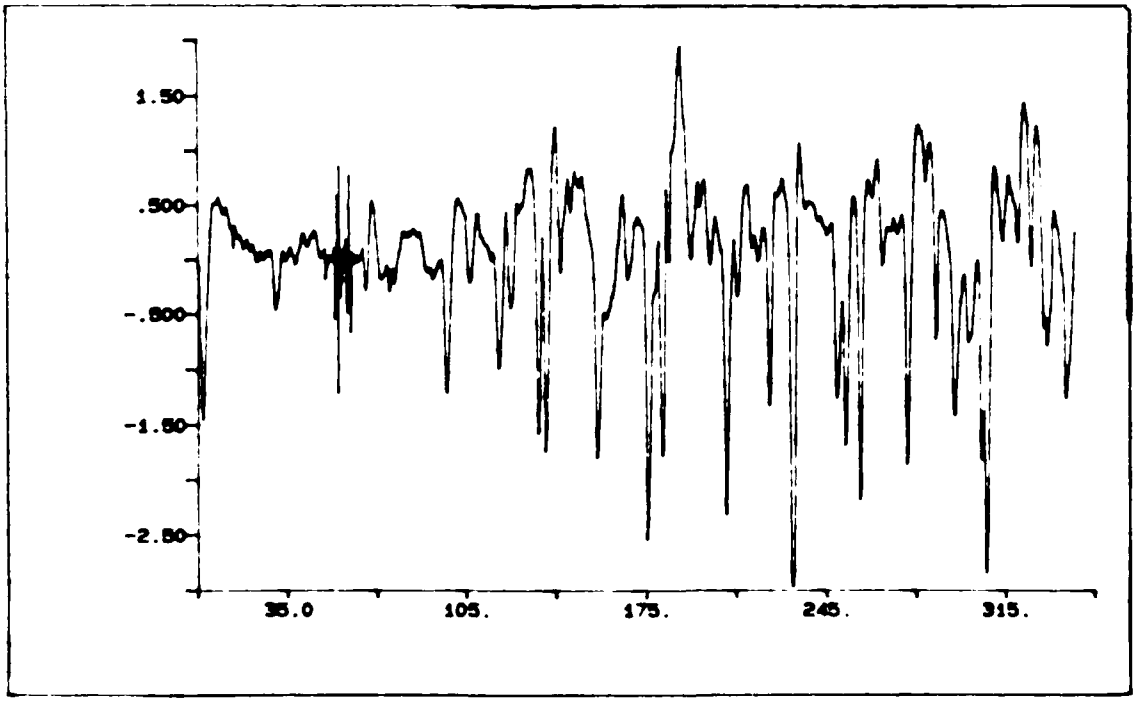

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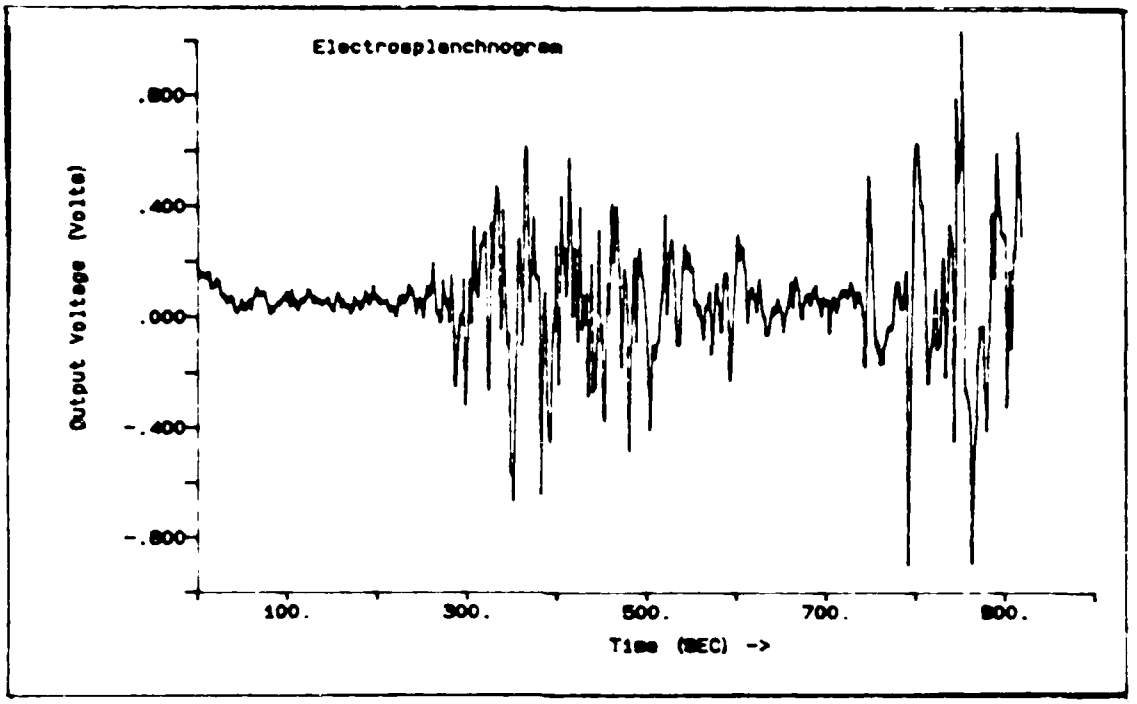

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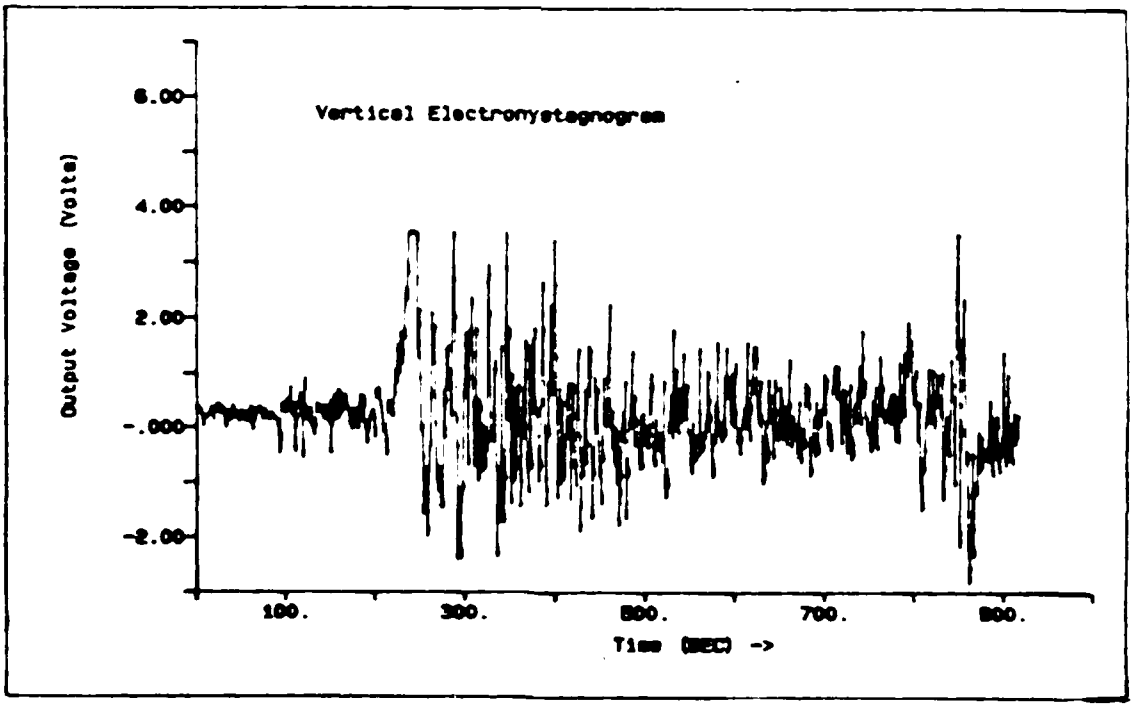
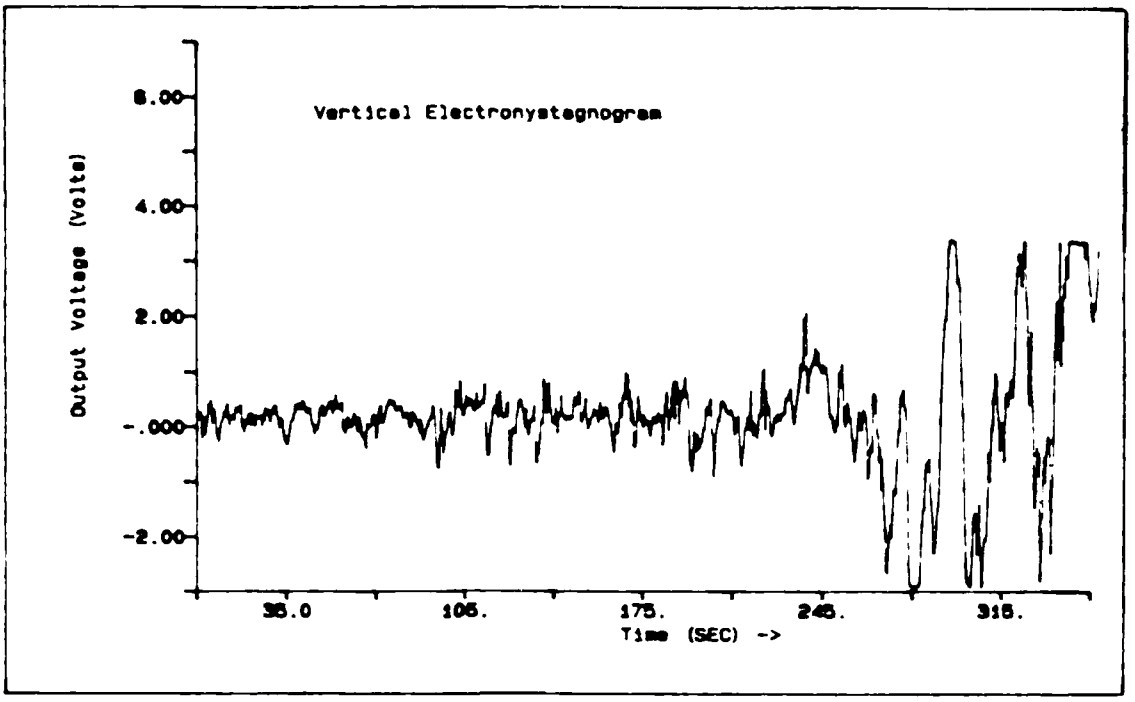


Figure 45. Vertical ENG as a Function of Time



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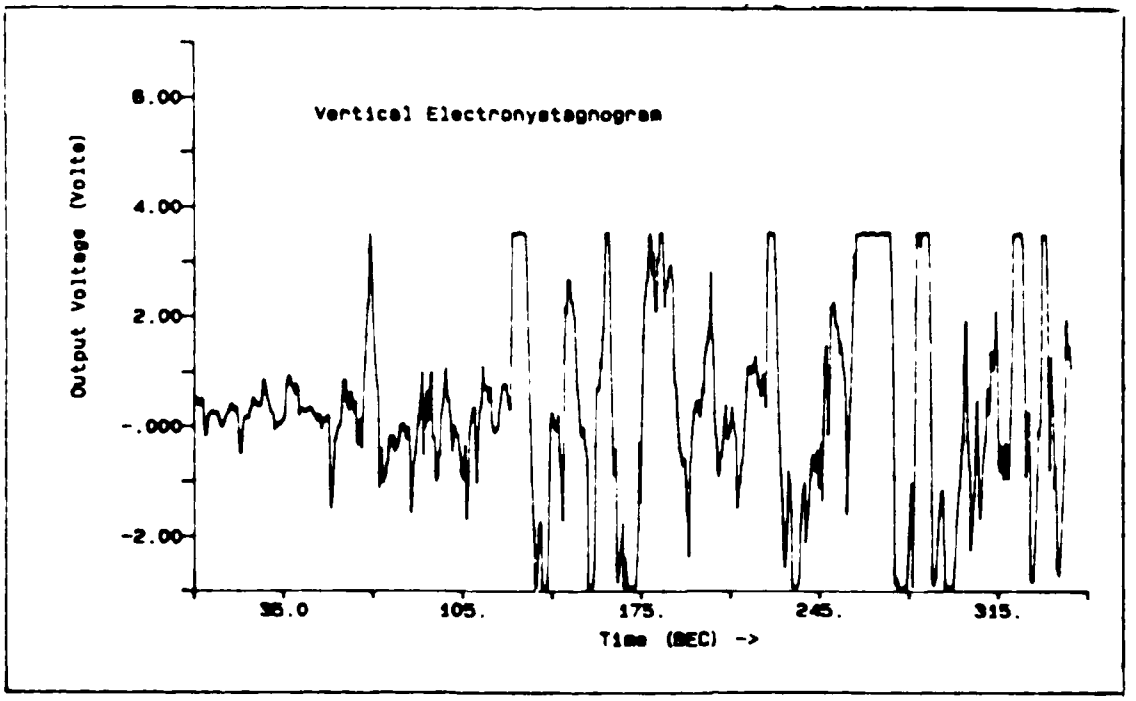

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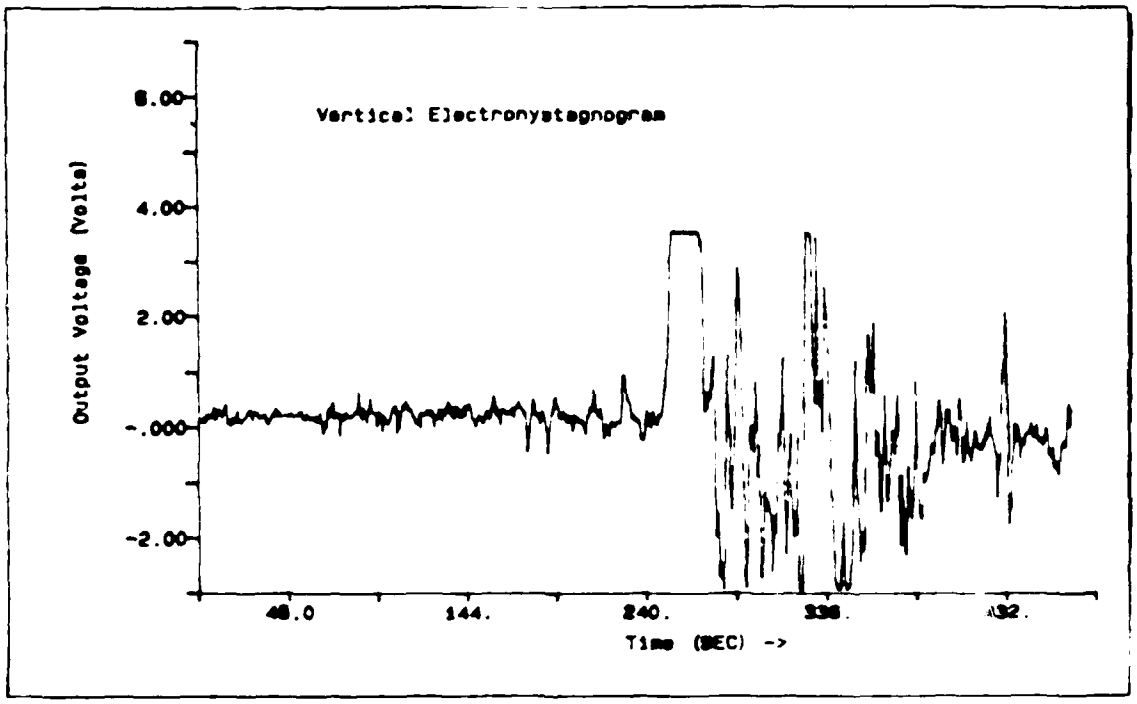

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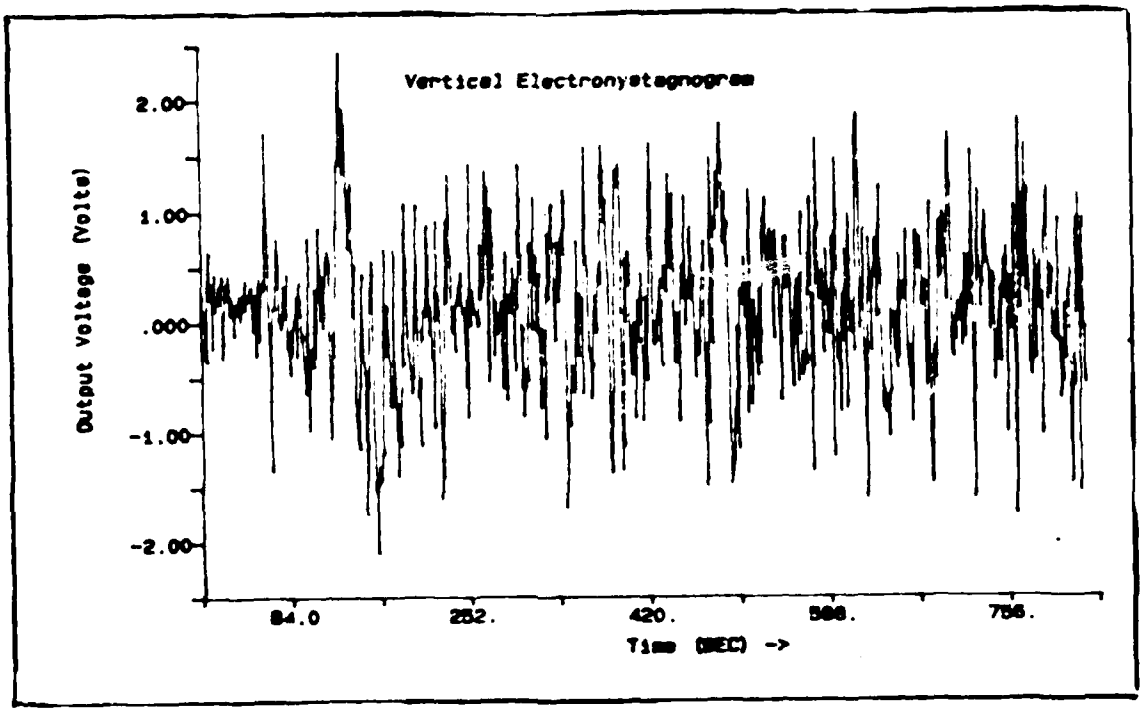

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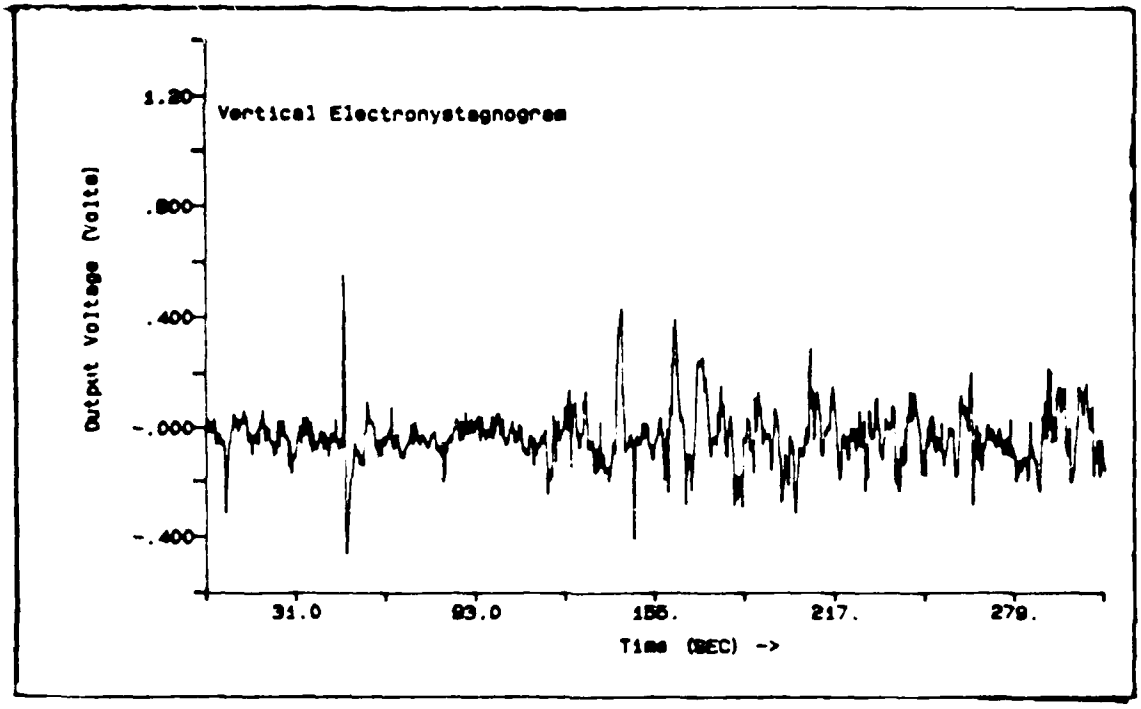

Figure 50. Vertical ENG as a Function of Time

BIBLIOGRAPHY

1. Czelen, W. E., Research Contractor, AFIT/ENG. Personal interviews. AFIT/EN, Wright-Patterson AFB, OH, March 1987 to October 1987.

2. Dhenin, Air Marshall Sir Geoffrey, Group Captain J. Ernsting, and Wing Commander G.R. Sharp. Aviation Medicine: Physiology and Human Factors. London: Tri-Med Books Limited, 1978.

3. Fitzpatrick, D. G. and others. Computerized Biophysical Data Acquisition System for Motion Sickness Studies. MS thesis, AFIT/GE/GCS/ENG/84D-30. School of Engineering, Air Force Institute of Technology (AU), Wright Patterson Air Force Base, OH, December 1984.

4. Gillingham, K. and J. W. Wolfe. "Spatial Orientation in Flight," Fundamentals of Aerospace Medicine, edited by Roy L. DeHart. Philadelphia:Lea and Febiger, 1985.

5. Graybiel, A. and others. "Diagnostic Criteria for Grading the Severity of Acute Motion Sickness, Aerospace Medicine, 39: 453-455 (May 1968).

6. Hartle, Dana R. A Motion Sickness Prediction Model and System Description. MS thesis, AFIT/GCS/ENG/86D-3. School of Engineering, Air Force Institute of Technology (AU), Wright Patterson Air Force Base, OH, December 1986.

7. Isu, N., Koo, J., and N. Takahashi. "Changes of Skin Potential Level and of Skin Resistance Level Corresponding to Lasting Motion Discomfort", Aviation, Space, and Environmental Medicine, 58: 136-142 (February 1987).

8. Jarvis, N. R. and C. T. Uyeda. An Analysis of Potential Predictive Parameters of Motion Sickness Using a Computerized Biophysical Data Acquisition System. MS thesis, AFIT/GSO/ENG/85D-1. School of Engineering, Air Force Institute of Technology (AU), Wright Patterson Air Force Base, OH, December 1985.

9. Kabrisky, M. Professor, AFIT/ENG. Personal interviews AFIT/EN, Wright-Patterson AFB, OH, March 1987 to November 1987.

10. Lackner, J. R., Ph.D and A. Graybiel. M.D. "Etiological Factors in Space Motion Sickness", Aviation, Space, and Environmental Medicine, 54: 675-681 (August 1983).

11. Levey, R. A. and others. "Biofeedback Rehabilitation of Airsick Aircrew", Aviation, Space, and Environmental Medicine, 52: 118-121 (February 1981).

12. Matsnev, E. I., and D. Bodo. "Experimental Assessment of Selected Antimotion Drugs", Aviation, Space, and Environmental Medicine, 55 : 281-286 (April 1984).

13. McPherson, Michael R. A Collection and Statistical Analysis of Biophysical Data to Predict Motion Sickness Incidence. MS thesis, AFIT/GCS/ENG/86D-14. School of Engineering, Air Force Institute of Technology (AU), Wright Patterson Air Force Base, OH, December 1986.

14. Miller, E. F., Ph.D., and A. Graybiel. "A Provocative Test for Grading Susceptibility to Motion Sickness Yielding a Single Numerical Score." Acta Otolaryngologica, Supplement 274, Naval Aerospace Medical Institute, Pensacola, Fla., 1970

15. Miller, Robert D. Motion Sickness: A Study of its Etiology and a Statistical Analysis. MS thesis, AFIT/GCS/ENG/86D-2. School of Engineering, Air Force Institute of Technology (AU), Wright Patterson Air Force Base, OH, December 1986.

16. Royal, L., Jenssen, B., and M. Wilkins. "Motion Sickness Susceptibility in Student Navigators," Aviation, Space, and Environmental Medicine, 55: 277-280 (April 1984).

17. Warwick-Evans, L.A. and others. "Electrodermal Activity as an Index of Motion Sickness," Aviation, Space, and Environmental Medicine. 58: 417-423 (May 1987).

VITA

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Department of Electrical Engineering

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Block 19. Abstract

The existing data acquisition system was modified to produce better accuracy of the measured data. Additional sensors were added, sensor types and placements were modified. Circuits were modified to prevent overloading and to allow better tracking of the full range of expected physiological data points.

Previous indicators were evaluated as to their accuracy and degree of their usefulness in a real-time processor.

A susceptibility test was developed to allow the classification of a person as to their level of motion sickness susceptibility.

Physiological data were analyzed on the basis of their relationship with the onset of motion sickness, to develop a motion sickness indicator.

END

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